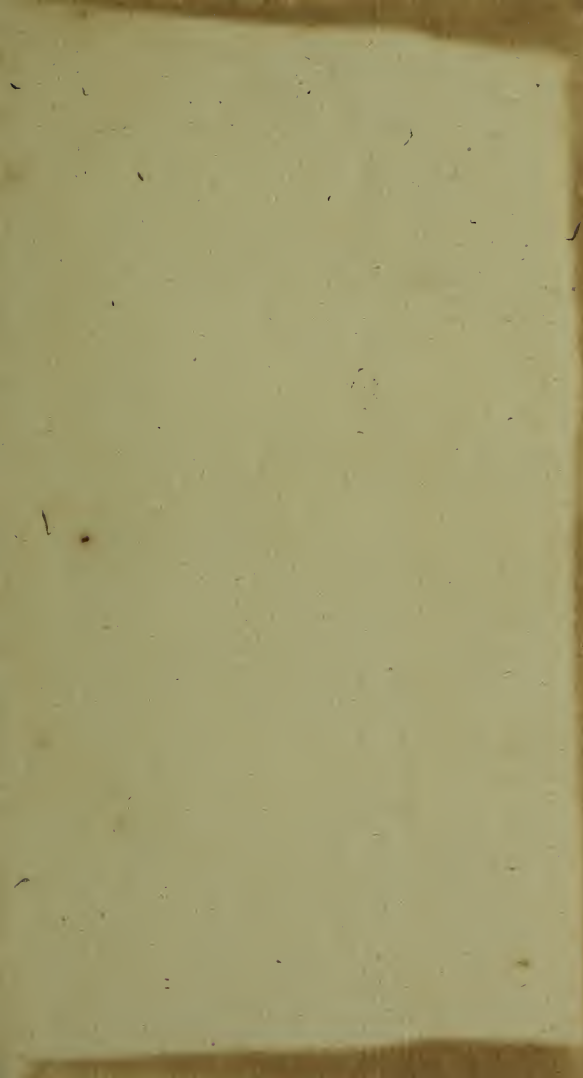


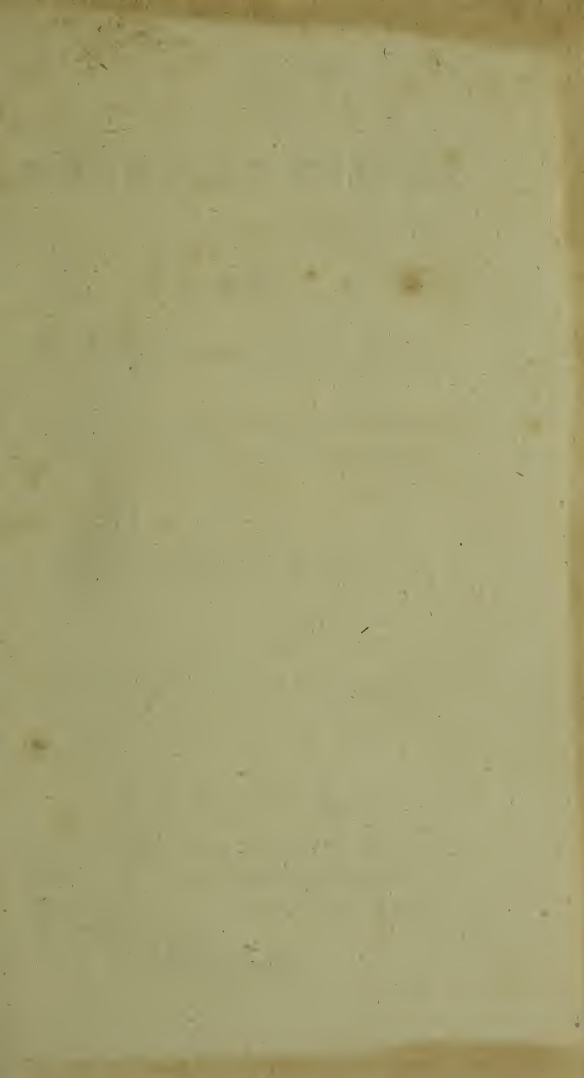
3 vols. - Complete -
see Preface vol. 3

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Vol. 1







CHEMICAL ESSAYS.

BY

R. WATSON, D.D. F.R.S.

AND REGIUS PROFESSOR OF DIVINITY IN
THE UNIVERSITY OF CAMBRIDGE.

VOL. I.

SECOND EDITION.

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MDCCLXXXII.



TO
HIS GRACE
THE
DUKE OF RUTLAND.

MY LORD DUKE,

YOUR GRACE, whilst I had
the honour of being in-
trusted with your Education in
this place, shewed a disposition
to the Study of Chemistry: I wish
that any thing contained in the

following Essays may tend to revive it.

Chemistry is cultivated abroad by persons of the first Rank, Fortune, and Ability ; they find in it a never failing source of honourable amusement for their private hours ; and as public men, they consider its cultivation as one of the most certain means of bringing to their utmost perfection, the manufactures of their country.

That

That your GRACE's private life may continue to be blessed with every domestic comfort ; and that your public life may be distinguished by principles and actions useful to your country, and honourable to yourself, is the sincere prayer of

Your GRACE's

Most affectionate

And obliged Servant,

Cambridge,
Feb. 20, 1781.

R. WATSON.

REFERENCE

The following is a list of references
to the literature on the subject of
the history of the United States
from the time of the first
settlements to the present
time. The references are
given in alphabetical order
of the authors' names.
The references are given in
the following order: 1. The
author's name, 2. The title
of the work, 3. The place
of publication, 4. The year
of publication, 5. The
publisher's name.

P R E F A C E.

TH E subjects of the following Essays have been chosen, not so much with a view of giving a System of Chemistry to the world, as with the humbler design of conveying, in a popular way, a general kind of knowledge, to persons not much versed in chemical inquiries.

Two other volumes, which are nearly ready for the press, would finish the whole of my plan ; but being quite doubtful how far either the subject itself, or at least, how far the manner in which I have been able to treat it, may be acceptable to the Public, I dare not at present venture to solicit the Reader's attention

P R E F A C E.

tion to them : if they should never see the light, the world will suffer little loss ; and as to the trouble and expence which I have been at in composing them, they are more than compensated by the knowledge I have gained.

There are two sets of men of whom I particularly crave indulgence — Chemists, and Divines. Chemists must excuse me, as well for having explained common matters, with what will appear to them a disgusting minuteness, as for having passed over in silence some of the most interesting questions : such are those which respect the analysis of air and fire, the production and transmutation of saline substances, the spontaneous destruction and generation of minerals.

Divines,

P R E F A C E.

Divines, I hope will forgive me, if I have stolen a few hours, not, I trust, from the duties of my office, but certainly from the studies of my profession, and employed them in the cultivation of natural philosophy: I could plead in my defence the example of some of the greatest characters, that ever adorned either this University or the Church of England. The books of Nature and of Revelation equally elevate our conceptions, and incite our piety; they mutually illustrate each other; they have an equal claim to our regard, for they are both written by the finger of the ONE ETERNAL INCOMPREHENSIBLE GOD, TO WHOM BE GLORY FOR EVER, AMEN.

For

P R E F A C E.

For the mistakes I may have fallen into in treating of such a variety of matter, and for the imperfection in the design and execution of the Work itself, I generally intreat the Reader's excuse in the words of Pliny,

*Occupati sumus officiis, subsecivisque
horis ista curamus.*

C O N-

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ESSAY

E S S A Y I.

On the Rise and Progress of Chemistry.

THE beginnings of every art, which tended either to supply the necessities, or to alleviate the more pressing inconveniences of human life, were probably coeval with the first establishment of civil societies, and preceded by many ages, the invention of letters, of hieroglyphics, and of every other mode of transmitting to posterity the memory of past transactions. In vain shall we inquire who invented the first plough, baked the

first bread, shaped the first pot, wove the first garment, or hollowed out the first canoe. Whether men were originally left, as they are at present, to pick up casual information concerning the properties of bodies, and to investigate by the strength of natural genius the various relations of the objects surrounding them; or were, in the very infancy of the world, supernaturally assisted in the discovery of matters essential, as it should seem, to their existence and well-being, must ever remain unknown to us.

There can be little doubt that in the space of, at least, 1656 years, from the creation of the world to the deluge, a great variety of economical arts must have been carried to a very considerable degree of perfection. The knowledge of many of these perished,

rished, in all likelihood, with the then inhabitants of the earth; it being scarcely possible for that single family which escaped the general ruin to have either practised, or been even superficially acquainted with them all. When men have been long united in civil societies, and human nature has been exalted by a reciprocal communication of knowledge, it does not often happen, that any useful invention is entirely lost: but were all the present inhabitants of the earth, except eight persons, to be destroyed by one sudden calamity, who sees not that most of those serviceable and elegant arts, which at present constitute the employment, and contribute to the happiness of the greatest part of the human race, would pro-

bably be buried in long oblivion? Many centuries might slip away, before the new inhabitants of the globe would again become acquainted with the nature of the compass, with the arts of painting, printing, or dying, of making porcelane, gun-powder, steel, or brass.

The interval of time which elapsed from the beginning of the world to the first deluge, is reckoned by profane historians, to be wholly uncertain as to the events which happened in it: it was antecedent, by many centuries, not only to the æra when they supposed history to commence, but to the most distant ages of heroism and fable. The only account relative to it, which we can rely upon, is contained in the first six chapters of the book of Genesis; three of which being employed in

the history of the creation, and of the fall of man; and a fourth containing nothing but a genealogical narration of the patriarchs from Adam to Noah; it cannot reasonably be expected, that the other two should enable us to trace the various steps by which the human intellect advanced in the cultivation of arts and sciences, or to ascertain, with much precision, the time when any of them was first introduced into the world. It is somewhat remarkable that from this account, short as it is, the chemists should be authorized, with some propriety, to exalt the antiquity of their art to the earliest times. Tubal-cain is there mentioned as an instructor of every artificer in copper and iron*. This circumstance proves beyond dispute, that

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one

* Gen. iv. 22.

one part of metallurgic chemistry was well understood at that time, for copper and iron are of all the metals most difficultly extracted from their ores, and cannot, even in our days, be rendered malleable without much skill and trouble; and it proves also that the arts in general were in an improved state amongst the antediluvians. It is said, indeed, that some tribes of Hottentots (who can have no pretensions to be ranked amongst the cultivators of the arts) know how to melt both iron and copper†; but this knowledge of theirs, if they have not derived it from an intercourse with the Europeans, is a very extraordinary circumstance, since the melting and manufacturing of metals are justly considered, in general,

† Forster's Voy. Vol. I. p. 81.

neral, as indications of a more advanced state of civilization than the Hottentots have yet arrived at. But not to dwell upon this; Cain we know built a city, and some would thence infer that metals were in use before the time of Tubal-cain, and that he is celebrated principally for his ingenuity in fabricating them for domestic purposes. History seems to support our pretensions thus far. As to the opinion of those who, too zealously contending for the dignity of chemistry, make the discovery of its mysteries to have been the *pretium amoris* which angels paid to the fair daughters of men, we in this age are more disposed to apologize for it than to adopt it. We may say of arts what the Roman historian has said of states—*datur*

hæc venia antiquitati, ut, miscendo humana divinis, primordia artium augustiora faciat §.

For many ages after the flood we have no certain accounts of the state of chemistry. The art of making wine indeed, was known, if not before, soon after the deluge; this may be collected from the intoxication of Noah ||, there being no inebriating quality in the unfermented juice of the grape. The Egyptians were skilled in the manufacturing of metals, in medicinal chemistry, and in the art of embalming dead bodies, long before the time of Moses, as appears from the mention made of Joseph's cup *, and from the physicians being ordered to embalm the body of Jacob †. They practised
also

§ Livy's Præf. || Gen. ix. 21.

* Gen. xliv. 2. † Gen. l. 2.

also the arts of dying and of making coloured glass at a very early period; as has been gathered, not only from the testimony of Strabo, but from the relics found with their mummies, and from the glass beads with which their mummies are sometimes studded §. But we cannot from these instances conclude that chemistry was then cultivated as a separate branch of science, or distinguished in its application, from a variety of other arts which must have been exercised for the support and convenience of human life. All of these had probably some dependence on chemical principles, but they

§ See Delaval's ingenious Inquiry into the Cause of the Changes of Colours, Pref. LVI: and Dutens's learned Inquiry into the Discoveries attributed to the Moderns, p. 241.

they were then, as they are at present, practised by the several artists without their having any theoretical knowledge of their respective employments. Nor can we pay much attention in this inquiry to the obscure accounts which are given of the two great Egyptian philosophers, Hermes the elder, supposed to be the same with Mizraim grandson of Noah; and Hermes surnamed Trismegistus the younger, from whom chemistry has by some been affectedly called the Hermetic art.

The chemical skill of Moses, displayed in his burning, reducing to an impalpable powder, and rendering potable the golden calf in the wilderness, has been generally extolled by writers on this subject; and constantly adduced as a proof of the
 then

then flourishing state of chemistry amongst the Egyptians, in whose learning he is said to have been well versed. If Moses had really reduced the gold of which the calf consisted, into ashes, by calcining it in the fire; or made it any other way soluble in water, this instance would have been greatly in point; but neither in Exodus nor in Deuteronomy where the fact is mentioned, is there any thing said of its being dissolved in water. The enemies of revelation on the other hand, conceiving it to be impossible to calcine gold, or to render it potable, have produced this account as containing a proof of the want of veracity in the sacred historian. Both sides seem to be in an error; Stahl and other chemists have shewn that it is possible to make
gold

gold potable, but we have no reason to conclude that Moses either used the process of Stahl, or any other chemical means for effecting the purpose intended—*he took the calf which they had made, and burnt it in the fire, and ground it to powder, and strewed it upon the water, and made the children of Israel to drink of it**. Here is not the least intimation given of the gold having been dissolved, chemically speaking, in water; it was stamped and ground, or, as the Arabic and Syriac versions have it, filed into a fine dust, and thrown into the river of which the children of Israel used to drink: part of the gold would remain, notwithstanding its greater specific gravity, suspended for a time, (as happens in the washing of copper

* Exod. xxxii. 20.

per and lead ores,) and might be swallowed in drinking the water, the rest would sink to the bottom, or be carried away by the flux of the stream.

Nevertheless, though nothing satisfactory can be concluded concerning the Egyptian chemistry from what is said of Moses in this instance, yet the structure of the ark, and the fashion of Aaron's garments, clearly indicate to us that the arts of manufacturing metals, of dying leather red and linen blue, purple, and scarlet ; of distinguishing precious stones, and engraving upon them, were at that time practised in a very eminent degree *. The Israelites had unquestionably learned these arts in Egypt, and there is great reason

* Exod. xxvi. and xxviii.

son to suppose not only that learning of every kind first flourished in Egypt, but that chemistry, in particular, was much cultivated in that country when other sciences had passed into other parts of the world. Pliny in speaking of the four periods of learning which had preceded the times in which he lived, reckons the Egyptian the first : and Suidas, who is thought to have lived in the tenth century, informs us that the Emperor Diocletian ordered all the books of chemistry to be burned, lest the Egyptians learning from them the art of preparing gold and silver, should thence derive resources to oppose the Romans *. It is worthy of notice that Suidas uses the word chemistry in a very restricted sense, when

when he interprets it by — the preparation of gold and silver ;—but all the chemists in the time of Suidas, and for many ages before and after him, were alchemists. The edict of Diocletian in the third century, had little effect in repressing the ardour for this study in any part of the world, since we are told that not less than five thousand books, to say nothing of manuscripts, have been published upon the subject of alchemy since his time *.

At what particular period this branch of chemistry, respecting the transmutation of the baser metals into gold, began to be distinguished by the name of alchemy, cannot be determined. An author of the fourth century, in an astrological work,

* Chem. Waller, p. 40.

work, speaks of the science of alchemy as well understood at that time; and this is said to be the first place in which the word alchemy is used*. But Vossius asserts that we ought in the place here referred to instead of *alchemia* to read *chemia* †: be this as it may, we can have no doubt of *alchemia* being compounded of the Arabic *al* (the) and *chemia*, to denote excellence and superiority, as in *al-manack*, *al-koran*, and other words. Whether the Greeks invented, or received from the Egyptians, the doctrine concerning the transmutation of metals, or whether the Arabians were the first who professed it, is uncertain. To change
iron,

* Jul. Fermi. Mater. Astronomicæ. Lib. 3. c. 15.

† Voss. Etymo. Vox Alchemia.

iron, lead, tin, copper, quicksilver into gold, seems to be a problem more likely to animate mankind to attempt its solution, than either that of squaring the circle, or of finding out a perpetual motion ; and as it has never yet been proved, perhaps never can be proved to be an *impossible problem*, it ought not to be esteemed a matter of wonder, that the first chemical books we meet with, are almost intirely employed in alchemical inquiries.

Chemistry, with the rest of the sciences, being banished from the other parts of the world, took refuge among the Arabians. Geber in the seventh, or as some will have it in the eighth, and others in the ninth century, wrote several chemical or rather alchemical books in

Arabic. In these works of Geber are contained such useful directions concerning the manner of conducting distillation, calcination, sublimation, and other chemical operations, and such pertinent observations respecting various minerals, as justly seem to entitle him to the character, which some have given him, of being the father of chemistry; though, in one of the most celebrated of his works, he modestly acknowledges himself to have done little else than abridge the doctrine of the ancients concerning the transmutation of metals*. Whether he was
pre-

* *Totam nostram metallorum transmutandorum scientiam, quam ex libris antiquorum philosophorum abbreviavimus, compilatione diversa, in nostris voluminibus, hic in unam summam redeimus. Gebri Alch. cap. 1. edition by Zetzner in 1512. In Tancken's edition in 1681, the words metallorum transmutandorum are omitted.*

ceded by Mefuè and Rhazes, or followed by them, is not in the present inquiry a matter of much importance to determine, since the forementioned phyficians as well as Avicenna, who, from all accounts, was pofterior to Geber, fpeak of many chéimical preparations, and thus thoroughly eftablifh the opinion, that medical chemiftry, as well as alchemy, was in thofe dark ages well underftood by the Arabians.

Towards the beginning of the thirteenth century Albert the Great in Germany, and Roger Bacon in England, began to cultivate chemiftry with fuccefs, excited thereto, probably, by the perufal of fome Arabic books, which about that time were tranflated into Latin. Thefe two monks, efpecially the

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latter,

latter, seem to have as far exceeded the common standard of learning in the age in which they lived, as any philosophers who have appeared in any country either before their time or since. They were succeeded in the fourteenth and fifteenth centuries, by a great many eminent men both of our own country and foreigners, who, in applying themselves to alchemy, made, incidentally, many useful discoveries in various parts of chemistry : such were Arnoldus de Villa Nova in France ; our countryman George Ripley ; Raymund Lully of Majorca, who first introduced or at least more largely explained the notion of an universal medicine ; and Basile Valentine, whose excellent book intitled *Currus Antimonii triumphalis*, has contributed more than any thing else

else to the introduction of that most
 useful mineral into the regular prac-
 tice of most physicians in Europe ;
 it has given occasion also to a va-
 riety of beneficial, as well as (a cir-
 cumstance which might be expect-
 ed, when so ticklish a mineral fell in-
 to the hands of interested empirics)
 to many pernicious *nostrums*. To
 this, rather than to the arrogant se-
 verity with which Basile Valentine
 treats the physicians his contempora-
 ries, may we attribute the censure of
 Boerhaave, who, in speaking of him,
 says, “ he erred chiefly in this, that
 he commended every antimonial
 preparation, than which nothing
 can be more foolish, fallacious, and
 dangerous ; but this fatal error has
 infected every medical school from
 that time to this †.” The

† Boerh. Ch. Vol. I. p. 18.

The attempting to make gold or silver by alchemical processes had been prohibited by a constitution of Pope John the xxii, who was elevated to the pontificate in the year 1316* ; and within about one hundred and twenty years from the death of friar Bacon, the nobility and gentry of England had become so infatuated with the notions of alchemy, and wasted so much of their substance in search of the philosopher's stone, as to render the interposition of government necessary to restrain their folly. The following act of parliament, which lord Coke calls the shortest he ever met with, was passed 5 H. 4. " None from henceforth shall use to multiply gold or silver, or use the craft of multiplication,

* Kirch. Mun. Sub. L. xi. Sect. iv. c. i.

tion, and if any the same do, he shall incur the pain of felony." It has been suggested, that the reason of passing this act was not an apprehension lest men should ruin their fortunes by endeavouring to make gold, but a jealousy lest government should be above asking aid of the subject. "After Raymund Lully, and Sir George Ripley, had so largely multiplied gold, the lords and commons, conceiving some danger that the regency, having such immense treasure at command, would be above asking aid of the subject, and might become too arbitrary and tyrannical, made an act against multiplying gold and silver †." This act, whatever might be the occasion of passing it, though it gave some

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† *Opera Mineralia explicata*, p. 10.

obstruction to the public exercise of alchemy, yet it did not cure the disposition for it in individuals, nor remove the general credulity; for in the 35 H. 6. Letters Patent were granted to several people, by which they were permitted to investigate an universal medicine, and to perform the transmutation of metals into real gold and silver, with a non-obstante of the forementioned statute, which remained in full force till the year 1689, when being conceived to operate to the discouragement of the melting and refining of metals, it was formally repealed *. The

* Mr. Boyle is said by his interest to have procured the repeal of this singular statute, and to have been probably induced thereto, in consequence of his having been persuaded of the possibility of the transmutation of metals into gold. See his Life prefixed to the folio ed. of his works, p. 83.

The beginning of the sixteenth century was remarkable for a great revolution produced in the European practice of physic, by means of chemistry. Then it was that Paracelsus, following the steps of Basile Valentine, and growing famous for curing the venereal disease, the leprosy, and other virulent disorders, principally by the means of mercurial and antimonial preparations, wholly rejected the Galenical pharmacy, and substituted in its stead the chemical. He had a professor's chair given him by the magistracy of Basil, was the first who read public lectures in medicine and chemistry, and subjected animal and vegetable as well as mineral substances to an examination by fire.

It seldom happens that a man of but common abilities, and in the
 most

most retired scenes of life, observes such a strict uniformity of conduct, as not to afford prejudice and partiality sufficient materials for drawing his character in different colours; but such a great and irregular genius as Paracelsus, could not fail of becoming alike, the subject of the extremes of panegyrick and satire. He has accordingly been esteemed by some, a second Esculapius; others have thought that he was possessed of more impudence than merit, and that his reputation was more owing to the brutal singularity of his conduct, than to the cures he performed. He treated the physicians of his time, with the most sottish vanity and illiberal insolence; telling them, that the very down of his bald pate had more knowledge than all their writers,

ters, the buckles of his shoes more learning than Galen or Avicenna, and his beard more experience than all their universities *. He revived the extravagant doctrine of Raymond Lully, concerning an universal medicine, and untimely sunk into his grave at the age of forty-seven, whilst he boasted himself to be in possession of secrets able to prolong the present period of human life to that of the Antediluvians.

But in whatever estimation the merit of Paracelsus as a chemist may be held, certain it is; that his fame excited the envy of some, the emulation of others, and the industry of all. Those who attacked, and those who defended his principles, equally promoted

* Preface to his book entitled *Paragranum*, where there is more in the same stile.

promoted the knowledge of chemistry ; which from his time, by attracting the notice of physicians, began every where to be systematically treated, and more generally understood.

Soon after the death of Paracelsus, which happened in the year 1541, the arts of mining and fluxing metals, which had been practised in most countries from the earliest times, but had never been explained by any writers in a scientific manner, received great illustration from the works of Georgius Agricola, a German physician. The Greeks and Romans had left no treatises worth mentioning upon the subject, and though a book or two had appeared in the German language, and one in the Italian, relative to metallurgy,

before

before Agricola published his twelve books *De Re Metallica*, yet he is justly esteemed the first author of reputation in that branch of chemistry.

Lazarus Erckern (assay-master general of the empire of Germany) followed Agricola in the same pursuit. His works were first published at Prague in 1574, and an English translation of them by Sir John Pettus, came out at London in 1683. The works of Agricola and Erckern are still highly esteemed, though several others have been published, chiefly in Germany, upon the same subject since their time. Amongst these we may reckon Schindler's Art of Assaying Ores and Metals; the metallurgic works of Orschall; the works of Henckell; of Schlutter; of Cramer; of Lehman; and

and of Gellert. Germany, indeed, has for a long time been the great school of metallurgy for the rest of Europe; and we, in this country, owe the present flourishing condition of our mines, especially of our copper mines, as well as of our brass manufactory, to the wise policy of queen Elizabeth, in granting great privileges to Daniel Houghsetter, Christopher Schutz, and other Germans, whom she had invited into England, in order to instruct her subjects in the art of metallurgy.

It was not, however, till towards the middle of the last century, that general chemistry began to be cultivated in a liberal and philosophical manner. So early as the year 1645 several ingenious persons in London, in order to divert their thoughts
from

from the horrors of the civil war which had then broken out, had formed themselves into a society, and held weekly meetings, in which they treated of, what was then called, the new or experimental philosophy. These meetings were continued in London till the establishment of the Royal Society in 1662; and before that time, by the removal of some of the original members to Oxford, similar meetings were held there, and those studies brought into repute in that university. Mr. Boyle, who had entered upon his chemical studies about the year 1647, was a principal person in the Oxford meetings: he published at that place his *Sceptical Chemist*, in 1661, and by his various writings and experiments

greatly

greatly contributed to the introducing into England, a taste for rational chemistry.

Next to Boyle, or perhaps before him as a chemist, stands his cotemporary the unfortunate Beccher, whose *Physica Subterranea*, justly intitled *opus sine pari*, was first published in 1669. After having suffered various persecutions in Germany, he came over into England, and died at London in 1682, at the age of 57. He resided some time before his death in Cornwall, which he calls the mineral school, owning that from a teacher, he was there become a learner. He was the author of many improvements in the manner of working mines, and of fluxing metals; in particular he first introduced into Cornwall the method

thod of fluxing tin by means of the flame of pit-coal, instead of wood or charcoal *.

Lemery's very accurate course of practical chemistry appeared in
1675.

* Beccher wrote his *Alphabetum Minerale*, at Truro in Cornwall, in 1682, not long before his death. In his dedication of this tract to Mr. Boyle, he has the following words :—“ *ignis ufus, ope flammarum lithantracum stannum et mineralia fundendi, Cornubiæ hætenus incognitus, sed a me introductus.*”—This account which Beccher gives of himself, is not quite agreeable to what is advanced by an author every way qualified to come at the truth of this matter.—“ Necessity at last suggested the introduction of pit-coal for the smelting of tin ore ; and among others, to Sir Bevil Granville of Stow in this county, temp. Car. I. who made several experiments, though without success ; neither did the effectual smelting of tin ore with pit-coal, take place till the second year of Queen Anne.” Pryce's *Miner. Cornub.* p. 282.

1675. Glauber's works had been published at different times, from 1651 to 1661, when his tract, entitled *Philosophical Furnaces*, came out at Amsterdam. Kunckel died in Sweden in 1702; he had practised chemistry for above 50 years, under the auspices of the Elector of Saxony, and of Charles XI. of Sweden. He wrote his chemical observations in the German language, but had them translated into Latin in the year 1677; the translation is dedicated by its author to our Royal Society. They were afterwards translated into English in 1704. Having had the superintendency of several glass-houses, he had a fine opportunity of making a great variety of experiments in that way; and I have been informed by our
 ena-

enamellers, and makers of artificial gems, that they can depend more upon the processes and observations of Kunckel, than of any other author upon the same subject. The chemical labours of these and many other eminent men, too numerous to mention, were greatly forwarded by the establishment of several societies, for the encouragement of natural philosophy, which took place in various parts of Europe about that period.

The Philosophical Transactions at London, the *Histoire de l'Academie Royale des Sciences* at Paris, the *Saggi d'Esperienze di Acad.* del Cimento at Florence, the *Journal des Sçavans* in Holland, the *Ephemerides Academiæ Naturæ Curiosorum*, in Germany, the Acts of the

Academy of Copenhagen, and the *Acta Eruditorum* at Leypsic ; all these works began to be published within the space of twenty years from 1665, when our Royal Society first set the example, by publishing the *Philosophical Transactions*. To these may be added, the works of the Academies of Berlin, Petersburg, Stockholm, Upsal, Bononia, Bourdeaux, Montpellier, Gottingen, and of several others which have been established within the course of the present century. Near a thousand volumes have been published by these learned societies within less than 120 years. The number of facts which are therein related respecting chemistry, and every other branch of natural philosophy, is exceedingly great ; but the
 subject

subject is still greater, and must for ever mock the efforts of the human race to exhaust it. Well did Lord Bacon compare natural philosophy to a pyramid ! Its basis is indeed the history of nature, of which we know a little, and conjecture much ; but its top is, without doubt, hid high among the clouds ; it is “ *the work which God worketh from the beginning to the end,*” infinite and inscrutable.

By the light which has been incidentally thrown upon various parts of chemistry from those vast undertakings of public societies, as well as from the more express labours of Stahl, Newman, Hoffman, Juncker, Geoffry, Boerhaave, and of many other equally worthy of commendation ; by the theoretic conclusions and systematic divisions

which have been introduced into it; from the didactic manner in which the students of this art have been instructed in every medical school; chemistry has quite changed its appearance. It is no longer considered merely in a medical view, nor restricted to some fruitless efforts upon metals; it no longer attempts to impose upon the credulity of the ignorant, nor affects to astonish the simplicity of the vulgar by its wonders, but is content with explaining them upon the principles of sound philosophy. It has shaken off the opprobrium which had been thrown upon it, from the unintelligible jargon of the alchemists, by revealing all its secrets in a language as clear and as common, as the nature of its subjects and operations will admit.

Con-

Considered as a branch of physics, chemistry is but yet in its infancy : however, the mutual emulation and unwearied endeavours of so many eminent men as are in every part of Europe engaged in its cultivation, will in a little time render it equal to any part of natural philosophy, in the clearness and solidity of its principles. In the utility resulting to the public from its conclusions, with respect to the practice of medicine, of agriculture, arts and manufactures of every kind, it is even in its present state inferior to none.

The uses of chemistry, not only in the medical, but in every economical art are too extensive to be enumerated, and too notorious to want illustration ; it may just be ob-

served, that a variety of manufactures, by a proper application of chemical principles, might, probably, be wrought at a less expence, and executed in a better manner than they are at present. But to this improvement there are impediments on every hand, which cannot easily be overcome. Those who by their situations in life are removed from any design or desire of augmenting their fortunes by making discoveries in the chemical arts, will hardly be induced to diminish them by engaging in expensive experimental inquiries, which not only require an uninterrupted attention of mind, but are attended with the wearisomeness of bodily labour. It is not enough to employ operators in this business; a man must

blacken his own hands with charcoal, he must sweat over the furnace, and inhale many a noxious vapour before he can become a chemist. On the other hand, the artists themselves are generally illiterate, timid, and bigotted to particular modes of carrying on their respective operations. Being unacquainted with the learned, or modern, languages, they seldom know any thing of new discoveries, or of the methods of working practised in other countries. Deterred by the too frequent, but much-to-be lamented examples of those, who, in benefiting the public by projects and experiments, have ruined themselves, they are unwilling to incur the least expence in making trials, which are uncertain with respect to profit. From this apprehension,

prehension, as well as from the mysterious manner in which most arts, before the invention of printing, and many still continue to be taught, they acquire a certain *opiniâtreté*, which effectually hinders them from making improvements, by departing from the ancient traditionary precepts of their art. It cannot be questioned, that the arts of dying, painting, brewing, distilling, tanning, of making glass, enamels, porcelane, artificial stone, common salt, sal ammoniac, salt-petre, potash, sugar, and a great variety of others, have received much improvement from chemical inquiry, and are capable of receiving much more.

Metallurgy in particular, though one of the most ancient branches of chemistry, affords matter enough for
new

new discoveries. There are a great many combinations of metals which have never been made ; many of which, however, might be made, and in such a variety of proportions, as, very probably, would furnish us with metallic mixtures more serviceable than any in use. The method of extracting the greatest possible quantity of metal from a given quantity of the same kind of ore, has, perhaps, in no one instance been ascertained with sufficient precision. There are many sorts of iron and copper ores which cannot be converted into malleable metals, without much labour, and a great expence of fuel ; it is very probable, that by a well-conducted series of experiments, more compendious ways of working these minerals might

might be found out. In our own times three new metallic substances have been discovered*, and their properties abundantly ascertained by experiment; and it may reasonably be conjectured, that future experience will yet augment their number. Till Marggraf shewed the manner of doing it, no metallic substance could be extracted from calamine, and all Europe was supplied with zinc † either from India or from Germany. A manufactory of this metallic substance has not many years ago been established in our own country, and the copper works near Bristol have supplied Birmingham

* Platina, Regulus of Cobalt, Nickel.

† Zinc is a metallic substance, of the colour of lead; when united with copper, it constitutes brass, pinchbeck, and other metallic mixtures resembling gold.

ham with zinc extracted from calamine. *Black-jack* was not long since employed in Wales for mending the roads; its value is not yet generally known in Derbyshire; but it is now well understood by some individuals to answer the purpose of calamine for the making of brass*. Mons. Von Swab in 1738 was, I believe, the first person who distilled zinc from *black-jack* †; and a work which he erected, probably gave the hint to the establishers of our English manufactory: indeed, I have been well informed, that they purchased the secret from him when he

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* The cobalt ores in Hesse, which at present produce a net profit of about 14000*l.* a-year, were formerly used for the same purpose as *black-jack* was lately in Wales.—Born's Travels by Raspe, Pre. xxvi.

† Cronstedt's Miner. Sec. 231.

was in England. The various kinds of black lead, from which neither tin nor iron can at present be procured to advantage; the mundicks, some cobalt ores, cawk, kebble, and other mineral substances, which are now thought to be useless, may some time or other, perhaps, be applied to good purpose. Cawk and kebble, which are found in great quantities in mining countries, especially in Derbyshire, and which are universally thrown away, may, perhaps, be nothing but different kinds of spar, and destitute of all metallic matter*; yet it may not be improper to remark, that the external appearance of the yellowish cawk is wholly similar to that of calcined
black-

* See Mr. Woulfe's ingenious Experiments in Philos. Transf. 1779, p. 15.

black-jack. That it is much of the same weight as *black-jack*, may appear from the annexed table :

Weight of a cubic foot of

White cawk	4047	} avoirdup. oz.
Yellow cawk	4112	
Kebble	4319	
Black-jack	4093	
Water	1000	

In a word, the improvement of metallurgy, and the other mechanic arts dependent on chemistry, might best be made by the public establishment of an Academy, the labours of which should be destined to that particular purpose. The utility of such establishments has been experienced in Saxony and other places; and as mines and manufactures are to the full as important to us, as to any other European state, one may hope,

hope, that the constituting a *Chemical Academy* may, in times of peace and tranquility, become an object not unworthy the attention of the King or the Legislature of the British nation*.

* The reader who wishes to become more fully acquainted with the history of chemistry, may consult what Borrichius has said in his *Dissertation de Ortu et Progressu Chimiæ*, published at Copenhagen in 1668; and in his book entitled *Hermetis, Ægyptiorum, et Chemicorum sapientia ab Hermannii Curingii animadversionibus vindicata*, published at the same place in 1674. He will also find something worth his notice on this subject in Boerhaave's *Chemistry*; and in a work of Wallerius, called, *Chimiæ Physicæ Pars Prima*, published at Stockholm in 1760; where there is an useful catalogue of the most approved writers on the various parts of chemistry.

ESSAY

E S S A Y II.

On the principal Terms and Operations used in Chemistry.

THIS Essay, in which I mean to give a general account of the principal terms and operations used in chemistry, will, perhaps, be more troublesome to the reader, than any other which I shall have occasion to write : but he must not be discouraged, nor conceive a disgust against the science itself, from an inconvenience necessarily attending all sciences. Chemistry has as few technical terms belonging to it, as navigation, law, medicine, or any other art or science, which may have

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chanced to engage his attention. The more ancient chemists, indeed, were fond of coining abstruse terms, and frequent in the use of them; but this affectation is, at present, pretty generally and very justly exploded.

Of solidity and fluidity.

Though, in philosophical propriety of speech, water be as solid a body as a diamond, yet in the common acceptation of the word solidity, we consider it as opposed to fluidity. Natural philosophers have agreed to call that principle, by which the constituent parts of stones, glass, metals, and other substances cohere together, *Attraction*. They illustrate the agency of this principle, by a variety of decisive experiments;

ments ; decisive as to the proof of the existence of such a power, but indicating nothing at all of the cause of it. As the unknown principle of mutual attraction between the constituent parts of solid bodies, is the cause of their *solidity*, so the unknown principle of fire, is the cause of their *fluidity*. I call the principle of fire unknown, because, tho' its effects are sufficiently manifest, the cause of it is wholly questionable. But in whatever manner fire may be supposed to exert its agency, it seems to be the great instrument of fluidity upon the surface of the earth. Without a certain degree of heat, water, spirits of wine, oil, quicksilver, and perhaps the air itself, would be converted into solid bodies ; and with a certain degree

of heat all fluid bodies would be changed into elastic vapours, and all solid bodies would either be wholly dissipated, or in part dissipated, and in part converted into fluid glafs. These are extreme cases, to which no portion of the earth is obnoxious; no climate is so hot, but that it abounds with water in a state of fluidity; and none has yet been discovered so cold, but that the air and the blood, of aquatic animals at least, continue fluid in it.

Of volatility and fixity.

The changes produced in bodies by the action of fire are various, according to the constitution of the bodies themselves, and the degree of heat to which they are exposed. Some bodies, in a certain degree of
heat,

heat, may be wholly diffipated, others only in part, others not at all. Thus the same degree of heat which will intirely diffipate camphor, and convert water into vapour, will only produce a partial disperfion of the constituent principles of turpentine, blood, or milk; and will not effect any change or diminution of weight, in feveral woods, metals, earths, falts, and oils. Thofe bodies which by heat fuffer no diminution of their weight, are faid to be *fixed*, and thofe which do lofe of their weight, are faid to be *volatile*; and they are faid to be more or lefs volatile, according as a lefs or a greater degree of heat is requifite for producing a feparation of their parts. It is obvious, that *volatility* belongs to moft bodies, folid as well as fluid; fince the

heat of the atmosphere is sufficient to diminish the weight of many, and artificial applications of superior degrees of heat, that of many more : but it is not certain, whether absolute *fixity* belongs to any body in nature, since the same body which is fixed in one degree of heat, may become volatile in another : thus diamonds, which remain unchanged in a small degree of heat, may be wholly dissipated in open vessels by a greater ; and gold, which can resist the most violent fires excited in our furnaces, without losing any thing of its weight, may not be able to sustain the fiercer action of the solar rays, when united in the focus of a large burning-glass.

The fixity of bodies is not in proportion to their hardness, for a diamond

mond is harder than a ruby, yet a diamond may be wholly dissipated by a degree of heat which produces no manner of change in a ruby. We are indebted to the Emperor Francis I. for this experiment. He put diamonds and rubies, to the worth of six thousand florins, into different vessels, and exposed them to a violent fire for 24 hours; at the end of that time the vessels were taken out of the fire and opened, and there was not remaining the least vestige of the diamonds, the whole had been dissipated; but the rubies were found to have undergone no sort of change, either with respect to colour, shape, or weight*.

Of

* See Magasin de Hambourg, Tom. xviii. p. 164. or an extract in the notes annexed to Henckel's Works, published at Paris in 1760, Vol. II. p. 413.—Similar experiments have

*Of evaporation, volatilization,
exhalation.*

When solid or fluid bodies suffer a diminution of their weight, the parts which become volatile and fly away, are said to be *evaporated, volatilized, exhaled*, for these three terms are often used promiscuously, though it would be an easy matter to distinguish them. The parts themselves are either humid, such are those which are separated from all fluids, (except quicksilver) and the watery parts of solid bodies; or they are dry; such are the volatile parts separated from marble or chalk, during the burning of lime, from volatile
salts,

lately been made in France: See *Chymie par M. Baumè*, Vol. I. p. 105. A good translation of this excellent work is much wanted.

salts, and refin's of various kinds, by the heat of the atmosphere. The terms, evaporation, &c. as simply indicating a loss of weight, may be applied to both. Evaporation is not solely effected by the mediation of heat; strong dry winds in cold frosty weather, are often more powerful agents in promoting the evaporation of water and other fluids, than the greatest heat of the sun in summer. The superficial parts of fluids are the only ones which are evaporated either by heat or air; and hence, in similar circumstances, the quantity evaporated, in any definite portion of time, will be greater as the surface of the fluid is greater. For this reason, the pans in which brine is boiled for the making of salt, and the pits, in which sea water is evaporated

porated by the sun and air for the same end, are usually made very shallow, and of a large area; and a proper attention to this circumstance might be serviceable to sugar-bakers, confectioners, and other artists who are under the necessity of evaporating large quantities of water. However, as a fluid contained in a deep vessel, when heated to a certain degree, retains its heat longer than it would do, if it was spread over a shallower vessel, and heated to the same degree; it may become a doubt, whether the quantity evaporated in consequence of its retaining heat longer, may not be equal to or exceed the quantity evaporated from the shallower vessel, in consequence of its larger surface. It might, perhaps, be an useful problem

blem to determine, by more accurate experiments than any which have been hitherto made, the length, breadth, and depth of a vessel which, with the consumption of a definite quantity of fuel, would evaporate the greatest possible quantity of any fluid in a certain time.

Of distillation and sublimation.

Though, in the process of evaporation, the volatile parts of bodies are usually dispersed in the air, and the remaining ones only preserved, yet it often becomes necessary to collect the volatile parts themselves: when this is the case, proper vessels are made use of for the purpose, and the operation, if the parts are fluid, is called, *distillation*, from their being collected drop by drop, *stillatim*. If
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the volatile parts, when collected, are dry and in a concrete form, the process is called, *sublimation*, from the parts being driven upwards by the force of the fire, and collected at a distance from the remaining parts. The volatile parts thus collected, may in general be called sublimates; they are of different consistencies, some being in hard masses, others in the form of a fine powder. Chemists have agreed to apply the name of *sublimate*, to such as are in consistent masses, the others, they call *flowers*: thus we hear of *corrosive sublimate*, and of *flowers of sulphur*. The foot of a chimney is a matter sublimed from the fuel, and it comes under the denomination of flowers, or sublimate, according as it is of a powdery or consistent appearance. During

ring the smelting of lead ore, that impalpable substance which issues out of the chimney of the furnace, and falling upon the adjoining grounds, renders the grafs unwholesome for cattle, may properly be called the flowers of lead ore. This distinction between distillation, as collecting the fluid, and sublimation, as collecting the solid parts of bodies, is not always scrupulously adhered to; since the best authors speak of the distillation of sulphur, and of other bodies whose volatile parts are dry.

The chemists usually distinguish distillation into three kinds, according to the different manners in which the distilled vapour is collected. The vapour in all cases flies from the fire; hence when the fire is placed above the vessel which contains the matter

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to be distilled, the vapour in escaping from the fire, will descend, and being collected in a proper vessel, the distillation is said to be made, *per descensum*, by descent. When the fire is placed under the vessel containing matter to be distilled, the vapour will ascend, and the distillation is called, *per ascensum*, by ascent; this is the common manner of distilling low wines and spirits. Besides these two kinds of distillation, there is a third, which usually takes its denomination from the form of the vessel, in which the matter to be distilled, is put. This vessel is bent, and hollow, somewhat resembling in shape, a bullock's horn; it is from thence, called by the French, a *cornue*; more generally, from its curved shape, a *retort*. The lower and more
capa-

capacious part of the retort is called its belly ; this is sometimes made almost globular, that it may contain the more ; the tapering crooked part is called its neck, and this part is joined to the belly, with various degrees of obliquity, according to the use to which the retort is designed. A large pear, with a long bent neck, may give an idea of the shape of a retort. The matter to be distilled, be it liquid or solid, is put in at the neck : it descends into the belly of the retort ; the heat is applied to the belly ; the vapours in flying from the heat, strike against the upper side or roof, as it is called, of the retort ; finding no exit there, they are forced out laterally through the neck ; the neck of the retort is closely joined to another hollow vessel, which from
its

its office, in collecting the distilled vapour, is called the *receiver* or *recipient*; the distillation is said to be made, *per latus*, by the side, or *per retortam*, by the retort. The retorts are made of various materials, as of glass, iron, earth, according to the degree of heat to which they are to be exposed.

It is not certainly known when, or by whom, the art of distilling was first found out. A diligent searcher into antiquity, informs us, “ that about the year 1150, the Moors of Spain first introduced the art of distillery into the west of Europe, they having learned it from the African Moors, who had it from the Egyptians; but how long before the said African Moors had been in possession of this curious art, does not clearly appear.

appear. Certain it is that this art was not known to the ancient Greeks and Romans, since neither Pliny, nor any other Latin or Greek author makes mention of it*.”

To me it seems probable that the art of sublimation was known before that of distillation. The term *alembic* or *alambic*, is compounded of the Arabic particle *al* (the), and the Greek word *ambix*, a kind of cup, or cover of a pot ; it is now used to denote the whole of a certain distilling apparatus ; it formerly denoted only one part of it, namely the head, or that part in which the distilled matter was collected. Dioscorides is thought, by Suidas, to have been physician to the celebrated Queen Cleo-

* Anderson on Comm. Vol. I. p. 83.

Cleopatra; he certainly knew the manner of subliming quicksilver from its ore, and he calls that part of the apparatus, in which the sublimed quicksilver was collected, ambix*; the addition of a spout or beak to his ambix, would have furnished him with a complete instrument for distilling, as well as subliming. But no one who considers how near the ancients were to the discovery of printing without finding it out, can be surpris'd at their knowing sublimation, and at the same time being ignorant of distillation; for that Dioscorides was ignorant of the art of distilling, may be reasonably conjectured, when we consider the sad shift he was put to in order to collect an oil which arose from boiling

* L. v. c. 110.

ing pitch ; he orders a clean fleece of wool to be stretched over the pot in which the pitch was boiled, and the oil to be pressed out of the wool as often as it became sufficiently wet with it.

It must be owned, that this argument is not intirely conclusive against the opinion of those who think that the art of distillation was known to the more ancient Greeks and Romans. For Dioscorides might have had his reasons for making use of the contrivance here mentioned, though he had been acquainted with distillation. It seems most natural to expect some account of this process in the writings of the physicians Hippocrates and Galen, had they been acquainted with it ; but there are no passages in their works, from which

any certain conclusion can be drawn relative to their knowledge of this operation. Geber, the Arab, was well acquainted with it, for he has given us a chapter on the subject, in which he lays down rules for distilling *per descensum*, and *per ascensum*, but he says nothing of distillation *per retortam*. But distillation was known, to the Egyptians at least, some centuries before the age of Geber; for Zosimus of Panopolis in Egypt, who lived in the fourth century after Christ, if not sooner, has exhibited some figures of a distilling apparatus *. Of

* These figures may be seen in Borrichius' *Hermetis et Ægyptiorum sapientia*, p. 156. The word *Chemia* first occurs in the works of this Zosimus. He says, though one may wonder whence he got his information, that it was in use before the Deluge, and that it signifies

*Of dephlegmation, concentration,
rectification.*

The word *pblegm* usually denotes the most watery parts of bodies, and when these parts are separated, either wholly, or in a great degree, either by distillation or sublimation, the

signifies something concealed. The Arabic tongue, according to Bochart, furnishes us with the word *Kémi* signifying concealment, and thence he derives *Chemia*, rather than from *Cham* the Hebrew root. Egypt is called by Plutarch in *Osiride*, *Chemia*, which Ortelius expounds for *Chamia*, from *Cham* the son of Noah. As the Arabians do not always copy exactly the proper names they borrow from the Hebrew; may it not be conjectured, that the Arabic *Kémi* signifying concealment, was introduced into that language, from the secret and hieroglyphic manner, in which the priests of *Cham* (Egypt,) concealed their knowledge of chemistry and other arts?

the bodies, be they solid or fluid, are said to be *dephlegmated*. When the watery parts of any compound fluid, are by any means taken away, the remaining parts approach nearer to each other, and may on that account be said to be *concentrated*; though the term concentration is chiefly applied to the separation of water from acid liquors. It frequently happens that the products obtained by one operation, are not sufficiently pure and homogeneous, and that a second or third distillation or sublimation becomes necessary to exhibit them in a proper form: this process of purifying the same body, how often soever it be repeated, is called *rectification*. Thus when we hear of an oil, or volatile salt, eight or ten times rectified, we are to understand that

it

it has been so often redistilled or resublimed. If the impurity, to be taken away, be a simple phlegm, it is obvious that the terms rectification, concentration, and dephlegmation, may be synonymous; and indeed they are often used promiscuously. Thus weak vinous spirits, and weak vinegars, are rectified, concentrated or dephlegmated by frost; for the water contained in these fluids being frozen and taken away in the form of insipid ice, the remaining fluids become stronger.

Of the degrees of heat commonly used in chemistry.

From what has been said relative to the fixity and volatility of bodies, it may readily be conceived, that the operations of distillation, and subli-

mation, by which the volatile parts of bodies are collected, will require different degrees of heat, according to the nature of the body whose parts are to be distilled or sublimed. It would be endless to enter into all the fancies and contrivances of chemists upon this subject; yet there are four modes of applying heat, which, though they are not so well defined that the degree of each can be accurately ascertained, ought to be particularly noticed,—*the heat of boiling water*;—*a sand heat*;—*a naked fire heat*;—and *a solar heat*.

Water, highly rectified spirits of wine, and other homogeneous fluids, cannot be heated in open vessels, and in a given state of the air beyond a certain degree peculiar to each. As soon as they fully boil, no continuance or
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increase of fire can communicate to them any increase of heat ; hence a vessel, containing a body to be distilled, being exposed to the action of boiling water, all the parts of the body which are volatile, with the degree of heat in which water boils, will be elevated from the body*, and may

* This observation is not, probably, perfectly just.---It is a very remarkable phenomenon, that a vessel containing water will never *boil*, how long soever it be exposed to the action of *boiling* water. The reader may convince himself of this by an easy experiment. Fill a common bottle with water, put the bottle thus filled into a pan of water, so that the mouth of the bottle may be a little above the water in the pan ; set the pan on the fire, and when the water in the pan boils in the most violent manner, that in the bottle will be observed not to boil, and if its heat be examined by a thermometer of Fahrenheit's

may be collected in proper vessels, whilst the other parts, if the body consists of different principles, will remain at the bottom of the vessel. This heat of boiling water is one of the most definite degrees known in chemistry ; there are many delicate operations, especially on vegetables, in which it would be improper to use so great a heat as that of boiling water ; but it is not necessary to enlarge upon

Fahrenheit's scale, it will not be found to amount to above 202 degrees, whilst that of the boiling water in the pan is 212 degrees. Hence it should seem, that bodies, distilled in vessels exposed to the action of boiling water, do not experience the heat of boiling water. This phenomenon is mentioned from Bartholin's *Acta Medica*, in the *Philos. Trans.* for 1673, No. 97.—See also Professor Braun's *Exper. Nov. Comm. Petrop.* Tom. XII. p. 289.—and Rozier's *Journ.* 1773.

on this observation in this place. Boiling mercury, boiling lead, boiling copper, would afford other definite degrees of heat ; and boiling oil might be very properly used as a mean of distilling bodies, notwithstanding that oil thickens in boiling, and thereby becomes hotter as the more subtle parts are dispersed.

There are many bodies, and parts of bodies, which cannot be rendered volatile by the heat of boiling water ; these are usually distilled by immersing the vessel containing them in sand, and applying the fire so as to heat the sand ; for the sand gradually communicates its heat to the vessel which it touches : the sand is generally put into an iron pot ; it is evident, that the fire which is employed to heat the pot, may communicate

cate any degree of heat to the sand, from the smallest, to that which is sufficient to melt the iron, so that it would no longer hold the sand.--- When the heat is communicated to the vessel, containing the body to be distilled, through any medium, as that of boiling water, or hot sand, the body is said to be distilled in a water bath, or sand bath, the chemists having agreed to call the medium, serving for the communication of heat to the distilling or subliming vessel, a bath; and formerly, besides water and sand, they used vapour, iron filings, wood ashes, &c. for this purpose.

When neither the heat of boiling water, nor of ignited sand, is sufficient to separate the volatile parts of a body from the remainder; the
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vessel containing the body is exposed to a naked fire ; that is, it is surrounded with burning fuel, and by a contrivance in the structure of the furnace, the flame of the fuel is often made to reverberate upon it. This degree of heat is also indefinite; it may be augmented, by bellows and other means, to such a pitch as to melt the furnace containing the fuel, or the vessel containing the body to be distilled. The degree of heat which may be excited in furnaces is undoubtedly very great, yet it is far inferior to that of the sun's rays when collected into a focus by a burning glass or speculum: the force of this solar heat cannot, perhaps, be subject to any other limit, except what arises from the difficulty of forming large speculums.

Of

Of solution, saturation, and crystallization.

When the parts of a solid body, as common salt or sugar, are so united to a fluid, as water, that they compose with it an apparently homogeneous fluid, remain suspended in it, and do not destroy its transparency, the solid body is said to be *dissolved* in the fluid ; the operation is called *solution* ; the fluid, being looked upon as the principal agent in dissolving the body, (though all action is mutual and equal) is called the *solvent*, or more commonly, according to some silly or indelicate ideas of the alchemists, the *menstruum* ; the compound resulting from the union of the fluid and the body, is called a *solution* of this or that body,

body, in this or that *menstruum*. Thus we speak of a solution of common salt or sugar in water, of a solution of sulphur in oil of turpentine, of camphor in spirits of wine, of silver in aqua fortis, and so on. The term solution is also sometimes applied to the union of two fluids; thus the air is said to be dissolved in water, because all natural water contains air; and water is said to be dissolved in air, because the most transparent air contains a considerable portion of water: thus also various sorts of oils are said to be dissolved in spirits of wine. And lastly, solution is applied to the union of two solid bodies: thus glass is a compounded body resulting from the mutual solution of an earth and a salt.

It may be worth while to explain, a little more fully, the first and most obvious notion of solution ; that in which a solid body is united to a fluid. If you take an ounce of common salt, and throw it into a quart of water, it will fall to the bottom of the water, as an ounce of sand or chalk would do ; but it will not, like them, stay there ; in a very little time, especially if the water be stirred, the salt will intirely disappear, it will be uniformly dispersed through the whole body of the water, no one drop of water will contain more particles of salt than another, nor will any of them contain so much salt as it is able to do. For if you add another ounce of salt, that also will be dissolved, but not quite so speedily as the first ; and that will also be uniformly

formly diffused through the whole body of the water, so that each drop of water will now contain twice as much salt as it did before. This power which the water has of taking up and keeping suspended the particles of salt is not unlimited; you may add so much salt to it, that it will not dissolve one particle more: the water in that state is properly enough said to be *saturated*. All other menstruums are likewise said to be saturated, when they will not take up and keep suspended any more of the body dissolved in them: thus a pint of spirits of wine will only take up a definite portion of camphor; a pint of oil of turpentine will only keep dissolved a definite portion of sulphur; and a pint of aqua fortis will be so saturated with a definite portion

of silver, that it will have no sort of action upon any additional quantity which shall be put into it.

We do not know either the size or the shape of the particles of water, nor whether they are contiguous to each other, nor how they come to attract the particles of salt more strongly than they attract each other ; but it is, notwithstanding, to this prevalent *attraction*, that we attribute the solution of the salt in water, and of every other body in its proper menstruum. We are certain that every particle of water attracts to itself, and keeps suspended a particle of salt, of a definite weight ; otherwise an equal number of these particles, constituting drops or particles of equal bulks, would not have equal weights, nor contain equal

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quantities of salt, which we are certain they do. Now if we suppose a single particle of water to be evaporated, or any how taken away from a saturated solution of salt, then the particle of salt which was kept suspended by the attraction of that particle of water, must of necessity have a tendency to fall down to the bottom; because every other particle of water, being supposed to have as much salt united to it as it is able to sustain, can contribute nothing to its support; and if instead of one particle of water we suppose a thousand, or ten hundred thousand to be evaporated, then will a thousand, or ten hundred thousand particles of salt be left without any substance to support them; and having no surrounding fluid to hinder their mutual at-

tractions from taking place, they will coalesce together upon the surface of the solution from which the water has been evaporated, and by their union constitute a saline pellicle, which will be visible to the naked eye. This pellicle, as soon as it becomes heavy enough to overcome the tenacity of the fluid upon which it floats, will by its gravity descend from the surface where it was formed, to the bottom of the vessel containing the solution ; or, meeting with asperities on the sides, it may attach itself in part to them.

But the taking away a part of the dissolving fluid is not the only mean by which the particles of the dissolved body may be made to unite; there is another, and in many instances, full as efficacious a one, the
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taking away a part, not of the substance, but of the heat of the dissolving fluid. Thus if you put into a quart of boiling water as much saltpetre as it will dissolve, and filling a bottle with the boiling solution, instantly cork it up; then you are sure that no part of the water can escape; and if the diminution of the quantity of a menstruum was the only way by which the parts of the dissolved body could be made to unite, then would the particles of the dissolved saltpetre, in this instance, not unite at all, since there can be no diminution of the quantity of the dissolving water: you will, however, on the contrary, observe the particles of the salt coalescing together, as the solution grows cold, and forming large and regular crystals.

—The word *crystal* is derived from the Greek words *cryos*, frost, and *stellw*, to contract. The ancients supposed a particular mineral known by the name of *rock crystal*, to be nothing but congealed water; this mineral is of a determined angular figure, and hence all salts and other substances which, from being dissolved in menstrooms, or fused in fire, concrete into regular figures, are said to be *crystallized*.

There are a great many circumstances relative to the manner in which different salts crystallize, which cannot be insisted on in this place; one thing deserves particularly to be remarked,—that every salt in crystallizing, invariably assumes its own peculiar form. You may dissolve common salt, or salt-petre,

petre, a thousand times, and crystallize them as often by evaporating or cooling the water in which they are dissolved, yet will you still find the common salt will be constantly crystallized in the form of a cube, and the salt petre in the form of a prism; and if you examine with a microscope such saline particles as are not visible to the naked eye, you will observe these particles to be of the same shape with the larger masses. The definite figure appropriate to every particular species of salt, may admit a little variety from the accidental admixture of other bodies, or from some singular circumstances attending the evaporation and crystallization of the solution; but these varieties are foreign to the nature of the salt, and are not greater than what

attend almost every species of vegetables, and even of animals, from change of food and climate.

Here a large field of inquiry opens to our view; and though it be better, as Seneca has it, *de re ipsa quærere quàm mirari*; yet all our attempts to investigate the works of God, are weak and ineffectual: we feel his interference every where, but we cannot apprehend the nature of his agency any where. A blade of grass cannot spring up, a drop of rain cannot fall, a ray of light cannot be emitted from the sun, nor a particle of salt be united, with a never failing symmetry, to its fellow, without him: every secondary cause we discover, is but a new proof of the necessity we are under of ultimately recurring to him, as the one primary cause

cause of every thing. Yet notwithstanding this our utter inability to search far into the nature of things, philosophical inquiries are by no means without their use. He who finds his endeavours to comprehend the works of *creation*, checked at every turn; who understands that every the minutest part of this little earth, which is itself nothing, as it were, when compared with the infinity of the divine works, is to him one great miracle; will not be overzealous in affirming that God cannot interfere by his *providence*, in the management of what he hath made, or that he has interfered in this or that particular way. In the conscious abasement of his own intellect, which philosophy will have taught him, he will be cured of all attachment

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ment to system, whether it be a system of bigotry or infidelity : he will not be fond of anathematizing every one who cannot think with him in religious matters ; nor, on the other hand, will he contend that a revelation from God must be an impossibility, from any abstract notions he may have framed of the nature and works of the Supreme Being. But to return to our subject.

If what has been said relative to crystallization, be not perfectly intelligible to the reader, I would advise him to make the following easy experiment, which will give him a better notion of the matter than a thousand words. Into a basin full of boiling water, put as much saltpetre as the water will take up ; if the saltpetre was purified, the transparency

sparcency of the water will not be injured, it will still appear to be an homogeneous fluid : when the water will take up no more saltpetre, then he may conclude that it is saturated : let it stand without being stirred, till it grows cold. As it cools, a great many crystals, all of the same shape, may be seen shooting out from the sides and bottom of the basin, and increasing in size till the solution becomes quite cold. When no more crystals can be formed by that degree of cold which prevails in the apartment where the experiment is made, pour the liquor from the solid crystals ; this liquor is still saturated with saltpetre ; and in order to make it part with more of its saltpetre, some of the water which keeps it dissolved must be evaporated : upon the
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taking away a part of the water, a correspondent part of the saltpetre loses the power by which it is suspended, and ought, upon that presumption, instantly to fall to the bottom : yet it must be remembered, that the water from its increased heat during the evaporation, is able to support more saltpetre than if it was cold ; and therefore the saltpetre will not begin to crystallize, notwithstanding the loss of part of its menstruum, till the remainder begins to cool. By repetition of this process of evaporation and crystallization, we may obtain all the saltpetre which was at first dissolved, as no portion of it can be evaporated with that degree of heat which is used in evaporating the water.

Of mixture and filtration.

There is a difference between *solution* and *mixture* sufficiently obvious, though not always attended to.--- Thus water which springs from chalk, has often, when the springs are low, a milky cast, arising from some very fine particles of chalk which are *mixed* with it, but not *dissolved*; in for perfect solution is always accompanied with transparency. Bristol and Matlock waters are very transparent, though they contain a large portion of earth; but the earth is in the state of a salt, and perfectly dissolved in them.--- Turbid waters, turbid solutions of salts, and other liquors which contain, mixed with their substance, any heterogeneous matter, are purified
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to a certain degree by *filtration*; that is, by being made to pass through certain substances, whose pores are large enough to give a passage to the particles of water, and to the particles of any salt dissolved in water, but not to the earthy or oily fœculences which may happen to be mixed with it. The substances made use of are called *filters*; they are either sand, or a porous kind of stone, thence called a filtering stone, or flannel, or linen, or leather, or brown paper into the composition of which no size has entered. This last substance is generally used in small chemical experiments; it is made up into a conical form, and placed in a funnel, or other convenient instrument to support it. Filters are serviceable instruments, not only for the purifying of liquors,
but

but for the separating of any kind of salt from a mixture of salt and earth, and enabling us to ascertain the proportion of salt and earth contained in any proposed specimen. An instance will illustrate my meaning. It is commonly known, that wood ashes, fern ashes, and the ashes of most vegetables, consist partly of a particular kind of salt, partly of earth. Suppose it was required to determine the proportion of salt and earth contained in any specimen of ashes, the process must be conducted in the following manner: — Take a pound of the ashes, previously well dried, boil them in a quart of water, pour the water and the ashes into a filter, the water will pass through the filter, bringing with it the salt contained in the ashes; for water dis-

solves

solves all kinds of salt, and no kind of earth : the earth therefore of the ashes will be left in the filter : wash the earth remaining in the filter, by pouring upon it hot water, till the water, in filtering through it, comes off wholly without taste ; then evaporate all the water in which the ashes were boiled, and with which the earth in the filter was washed, and when all the water is dissipated, there will be left a greyish kind of salt, of a very pungent taste. When this salt has been dried as much as the ashes were, it must be weighed whilst warm from the fire, and its weight noted ; then dry in the same manner the earth remaining in the filter ; and the weight of the earth thus dried, added to the weight of the salt, which has been extracted, will

will, when the experiment has been properly made, amount to the weight of the ashes employed in making it.

Of the analysis of bodies.

Most of the bodies which we meet with upon the surface of the earth or below it, are compounded of heterogeneous principles ; these principles must, in many instances, be separated from each other, before either the nature of the body can be properly understood, or the principles themselves be applied to any useful purpose. Thus the juice must be pressed from the earthy part of the grape, the sugar-cane, and the olive, before we can obtain either wine, sugar, or olive oil. The saline matter must be extracted from the earthy part of

the ashes mentioned in the last experiment, before it can in many cases become useful as a salt. Sulphur or arsenick, or both, must in many instances be separated from the ores of metallic substances, with singular care, before the metallic substances themselves can become articles of commerce ; or even before their existence, as constituent parts of the ores, can be made apparent. Many bodies, without any assistance from art, spontaneously resolve themselves into distinct principles ; thus blood, by standing, becomes separated into a watery fluid, and a red fleshy substance ; milk resolves itself in like manner into cream, into curd, and into whey. The process by which the heterogeneous parts of a compound body are separated from each other,

other, whether it be carried on by nature or art, may be called the *analysis, resolution, or decomposition* of the body.

It frequently happens, that the parts separated by one analysis, are themselves compounded bodies, and capable of being resolved, by a further process, into more simple principles. Just as in language, a sentence may be resolved into words, words into syllables, and syllables into letters ; so in the decomposition of natural bodies, we at last arrive at principles which do not admit any further resolution or change. These simple, unchangeable principles are called *elements* ; and it may, from what has been advanced, be readily apprehended, that the same substance may be esteemed an element by

one man, which is not so esteemed by another, according to the difference of their skill exerted in the analysis of bodies.

Of chemical elements.

By chemical elements, which are the last products of chemical analysis, we are to understand, not very minute indivisible particles of matter, but the simple homogeneous parts of bodies which are not capable, as far as our experience teaches us, of any farther resolution or division, except in a mechanical sense, into similar parts less and less without end, as water into vapour more or less subtle and attenuated. Aristotle and his followers esteemed *earth, air, fire,* and *water*, to be elements, simple and uniform in their several kinds, essentially

tially distinct, and utterly incapable of being converted into one another, yet easily uniting together, and by their different arrangements, proportions, and mixtures, composing every body in the universe. Many modern chemists have adopted this idea; others have increased the number of elements, by adding a saline principle; others have contended, that some of these elements, air and fire for instance, are themselves compound bodies; and others, lastly, are persuaded, that there is only one elementary homogeneous matter, and that all the varieties of bodies, as well as of what are commonly esteemed elements, ought to be attributed to the different magnitudes and figures of the particles composing them; and as the component parts

of water and air, or any other body, are by no means supposed to be elementary particles of matter, but to be made up of different numbers of elementary particles arranged in different forms, it may be thought probable, that mechanical causes may either diminish or augment the number, or change the disposition of the particles, and thus effect the several varieties observable in nature.

It would be improper in this place to enlarge on a subject, concerning which both ancient and modern philosophers have been so much divided in opinion : Their great diversity of sentiment may suggest a suspicion, that the full comprehension of it does not fall within the reach of the human understanding. The following observation may, perhaps, tend a little

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tle to illustrate this matter. Let us suppose that this terraqueous globe was not surrounded with any air or atmosphere, and that, by an approach to the sun, or an increase of the subterraneous fires, by some means or other it should become exposed to a heat four times greater than the medium heat of our summer, which we may reckon to be about 60 degrees of Fahrenheit's thermometer; then would an atmosphere be quickly formed around it: all the water upon its surface, most of the juices of plants and animals, and a great variety of mineral particles, would be raised up in vapours and exhalations, and whilst the heat continued would be kept suspended in an elastic state, and constitute an atmosphere analogous, as it may

sonably be imagined, to the chaotic state of our present atmosphere, only differing from it in this ; that it would require a greater degree of heat, in order to keep the particles of matter from coalescing into one heterogeneous mass. Again, in the present state of the atmosphere, suppose that a great degree of cold should continue unabated for any length of time ; all the water upon the surface of the earth would be changed into a solid transparent stone, which might be dug out of its quarry, and employed in building, as well as marble, or any other species of stone ; all the particles of air would be brought closer together ; some of them, which were the least elastic, would be re-united ; and imagining the cold to be indefinitely

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ly increased, what reason can there be against supposing that the whole atmosphere would be reduced into a solid state, forming an heterogeneous crust upon the surface of the earth: the thickness of this crust, supposing it to be as dense as marble, would be about four yards? It will easily be understood, that water, and air, and earth, are, upon this hypothesis, but variations of the same element introduced by heat.

That the atmosphere which surrounds the earth, was originally formed from the chaotic mass, by having the more subtile parts of which that mass consisted, elevated and put into an elastic state by means of heat, seems not altogether improbable. We find the atmosphere or firmament immediately suc-

succeeding the formation of light ;
 now, if the effect of that light was
 heat, be the form or matter of it
 what you please, then would such
 particles of the shapeless jumble,
 as were capable of being evaporated
 with that degree of heat, be elevated
 in an elastic state, and a division or
 separation would be made in the
 midst of the great abyss, between
 the waters which were of a nature
 subtile enough to be converted by
 that degree of heat into an elastic
 fluid, constituting the firmament or
 atmosphere, and the waters which
 could not be evaporated in that de-
 gree of heat, but still remained co-
 vering the surface of the globe, be-
 ing not collected into one place,
 that the dry land might appear, till
 the third day. This notion of the

atmosphere and its formation, seems to be conformable enough to Newton's opinion, expressed in his letter to Mr. Boyle. "I conceive the confused mass of vapours, air, and exhalations, which we call the atmosphere, to be nothing else but the particles of all sorts of bodies of which the earth consists, separated from one another, and kept at a distance by the said principle*,"—a principle of repulsion.

* Boyle's Life prefixed to the fol. edit. of his Works, p. 71.

ESSAY

E S S A Y III.

Of saline Substances.

IT may be expected that this disquisition should be commenced by giving a rigid definition of the term salt, or saline substance. But the complex ideas of natural substances are not subject to very definite descriptions. Nature, in her several productions, proceeds by imperceptible gradations, seldom leaving any decisive marks, by which we can invariably discriminate them into sorts. The two most general ideas which appertain to the word salt, are *sapidity* and *solubility*
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in water, and some add, want of inflammability in fire. Every substance soluble in water, and affecting the organ of taste with a sensation different from that excited by its weight, may be called a salt : I am sensible that this description of a salt cannot in all cases be closely adhered to, without confounding things sufficiently distinct. Copper by long mastication excites a nauseous taste, and by lying long in water it is in part dissolved in it, and yet we are not accustomed to class copper among saline substances.

If any one should wish to extend the meaning of the term salt, by applying it to all bodies which have regular figures, from some obscure notion, that a saline principle is the

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universal cause of crystallization, then a variety of spars and precious stones, glasses, and metallic substances, which are neither sapid nor soluble in water, would be rightly denominated salts; and water itself, when concreted into ice, would come under the same appellation. But leaving this more enlarged signification of the word salt, to the contemplation of those who are studious in the formation of sublime systems of nature; and confining ourselves to the more obvious properties of sapidity and solubility in water as characteristic of saline substances; we may proceed to observe, that all salts may be reduced to one or other of the three following kinds; they are either,—*acid salts*—*alkaline salts*—or *neutral salts*.

Of

Of acids.

The term *acid* explains itself by its ordinary acceptation ; for tho' there may be a great diversity in the tastes excited by different acid bodies, both with respect to intenseness and quality, yet no language has furnished distinct names for this variety. Sorrel, vinegar, cream of tartar, lemons, tamarinds, and a great many other bodies are all said to be acid when tasted ; and this capacity of exciting an acid taste, is one characteristic of an acid salt.

All those bodies, with a very few exceptions, which have an acid taste, have also, when sufficiently purified, the property of changing the blue colours of vegetables, as of syrop of violets into a red ; and
hence

hence this quality is reckoned another characteristic of an acid salt.

The great division of all terrestrial substances into minerals, vegetables, and animals, called the three kingdoms of nature, has suggested to chemists a division of acids into *mineral, vegetable, and animal acids*, according to the nature of the subject from which they are produced. The mineral acids may be copiously separated, by distillation, from *vitriol, nitre, and sea salt*; and in reference to these substances, they are usually called the *vitriolic acid*, the *nitrous acid*, and the *marine acid*.

—The vegetable acids are either *native*, such as exist in four fruits and plants; or *factitious*, such as *vinegar* and *tartar*, which are produced by fermentation. To the

class also of factitious vegetable acids, may be referred all the acids separable from vegetable matter by distillation; these generally retaining a burnt smell, are called *em-pyreumatic* acids: they have not hitherto been so fully examined as to be classed into different species. Animal acids are such as may be separated from various parts of animals by distillation; or they are such as bees, ants, and some other insects, contain in proper vessels ready prepared, and which they eject in stinging.

Of alkalies.

The term *alkali* is compounded of the Arabic particle *al* (the) and *kali*, the Arabic name of a maritime plant called by us *glasswort*, or *marsh samphire*. Glasswort is distinguished by

by botanists into the greater or lesser jointed glasswort, snail-seeded glasswort, prickly glasswort, &c. all of which are called kali; and from the ashes of them all, when thoroughly calcined, there may be washed out a salt, which is called an *alkali*, or an *alkaline salt*. If any one should think that the word kali is derived from an Hebrew root of nearly the same sound, signifying to burn; then he will conclude, that alkali originally had reference not to the name of any particular species of plants, but to the manner in which a salt might be procured from the ashes of burnt vegetables in general; and that in process of time a certain kind of plants came to be called kali, from its ashes abounding more, than those of any

other plant, with salt; just as *soda* or *soude*, from being the common name for this very salt, which is separated from kali, has become the French name for the plant itself*.

Kali is not the only maritime plant which yields an alkaline salt. On the coast of Spain, about Alicante and Carthagera, and, indeed, in many other countries bordering on the Mediterranean, the farmers sow their lands with the seeds of different sorts of maritime plants, which they pluck up at the proper season, dry in the sun as we dry hay, and burn to ashes. About Carthagera

* Kali herbam in cineram versam *Sodam* appellat vulgus. Baptis. Porta Mag. Nat. L. vi. C. 1. He describes the method of extracting the salt out of the ashes, and says that out of five pounds of the ashes they got one of salt.

gena they principally cultivate four sorts of plants, *barilla*, *gazul* or *algazul*, *soza*, and *salicornia*. The *barilla* yields the purest fixed alkali; each root of this plant sends out a great many stalks resembling samphire, and rising to about the height of four inches. The ground is much exhausted by the crop, it lies fallow every other year, and each acre produces about a ton of *barilla* *. Whether any of our salt marshes could be advantageously employed in this kind of culture, may deserve the serious consideration of those to whom they belong; certain it is, that plants which would yield this alkali, grow spontaneously upon several of them.

On the Orkney and Scilly isles, and on most parts of the British
H 3 coast,

Swinburne's Trav. through Spain, p. 130.

coast, great quantities of bladder fucus, or sea oak *, under the name of sea wrack, are annually burned in order to obtain an alkaline salt. The plants are cut from the rocks on which they grow, or gathered from the beach on which they are thrown by the tide; and being sufficiently dried by the heat of the sun in the summer season, they are set on fire; the fire-place is a hole in the ground; the ashes, to which the plants are reduced, are melted by the violence of the fire; the melted mass is kept in a state of fusion for three or four hours, it is then suffered to cool, and when it is set, they take it out of the hole in which the plants were burned, and the operation is recommenced. The solid mass procured from

* *Fucus vesiculosus*, Linnæi.

from the melting of the ashes of seawrack, is an article of great use in the making of glass and soap, and is known in commerce under the name of *kelp*, or *kelp ashes*. From kelp ashes may be extracted a salt, the same in every respect with that which may be procured from the ashes of kali or glasswort. The following experiment was made in order to ascertain the quantity of saline matter contained in British kelp.

Thirty ounces of kelp from the Orkneys, which had been previously pounded into a fine powder, and in that state well dried upon a hot iron, were boiled in various portions of water, till all the saline matter was extracted from the ashes; the water containing all the saline matter of the kelp was then evaporated with a

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gentle

gentle heat, and the salt which remained after the water was all evaporated, was further dried, as the kelp had been, upon a hot iron. The saline matter in that dry state weighed 19 ounces. The earth remaining after the extraction of the saline matter being carefully collected, and thoroughly dried upon a hot iron, it weighed exactly in that state 11 ounces. This experiment was repeated with the same success.

There is a much greater quantity of saline matter contained in Spanish barilla than in English kelp, as may be inferred from the following experiment. Spanish barilla, as well as English kelp, is mixed with several pieces of black matter; this matter consists of pieces of the plants which have been reduced to charcoal, but
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not to ashes, during the combustion of the plants. I pounded into a fine powder a quantity of barilla; the powder had a greyish cast from the charcoal it contained; it was dried upon a hot iron, and it lost by that operation one fourteenth of its weight. I took 30 ounces of this dried barilla, and proceeding as in the analysis of kelp ashes, I obtained 22 ounces of saline matter. It appears from hence, that there is three hundred weight more of saline matter in a ton and an half of barilla, than of kelp ashes.

It is very probable, that kelp ashes prepared in different countries, contain the earthy and saline parts in proportions different from those here ascertained; yet it is worth remarking, that the analysis here given coincides,

cides, as to the earthy part, with the experiments of one author, and as to the saline part, with the experiments of another. From 28 drachms of kelp ashes, Dr. Home obtained 10 drachms of earth; now the proportion of 30 to 11, is nearly the same with that of 28 to 10*.—M. Cadet obtained 6 pounds 3 ounces and an half of saline matter from 10 pounds of kelp ashes; if he had obtained one half ounce more, the proportion of saline matter procured from the kelp he examined, would have been almost exactly the same with that procured from the Orkney kelp which I examined †. I was not aware of the

* See his very ingenious Essay on Bleaching, p. 151.

† Hist. de l' Acad. des Sciences à Par. Ann. 1767, p. 488.

the experiments here referred to, when I undertook to ascertain the respective quantities of earth and saline matter contained in kelp ashes, and for that reason the coincidence may be the better relied on.

The reader may wonder, why, in speaking of the salt contained in kelp, I have called it by the general name, saline matter, in the very place where I was considering it as a particular kind of salt, as an alkali : this was not done without reason ; for not only kelp ashes, but the ashes of kali, barilla, and most maritime plants, besides an alkaline salt, contain a portion of common salt, and of some other kinds of salt, which it is not necessary here to enumerate. These foreign salts injure very much the purity of the alkali, for the obtaining

ing of which the plants are burned; and the British kelp ashes abound with them so much, that from some trials I have made I should conclude, that the 19 ounces of saline matter, which I had extracted from 30 ounces of kelp, did not contain above five ounces of pure mineral alkali free from water. The expression, free from water, requires an explanation.

The 19 ounces then of saline matter obtained from 30 ounces of kelp, were dissolved in water, and from the solution, when evaporated and crystallized, I obtained 12 ounces of alkaline salt in very fine transparent crystals. Since all attraction is mutual, it may readily be understood, that as the particles of water attract those of the alkaline salt, and retain them in solution, so the particles of the

the alkaline salt will attract those of the water, and retain them in crystallization. The water thus attracted by the particles of a salt during its crystallization, is usually denominated the *water of crystallization*.

This water of crystallization is contained in different quantities in different salts, and it adheres to them with different degrees of force; though it is easily separated from most of them, the moderate heat of the atmosphere being sufficient to evaporate it from many. When this water of crystallization is evaporated from any salt, the figure of the crystals is destroyed; the salt from being a solid transparent substance becomes an opaque powder. But though a salt, in losing its water of crystallization, loses its crystalline form, it does
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not thereby lose part of its saline quality ; for the water which is separated from it is pure water ; and the salt, by being redissolved in water and recrystallized, will not only regain its former figure, but the whole of its weight.

This observation respecting the water of crystallization is not without its use, either in medicine or trade. The salt known in medicine under the name of Glauber's salt, is one of those which contains near half its weight of water, wholly unessential to it as a salt : hence an ounce of Glauber's salt, in transparent crystals, has not more strength as a medicine, than half an ounce of the same salt when reduced to a powder, by having its water of crystallization evaporated. The twelve
 ounces

ounces of alkaline salt in question were exposed to a very gentle heat (they would have been melted by a strong one) till they were reduced to a fine powder : this powder was dried on a hot iron, and in that state it weighed not quite five ounces ; so that twelve tons of alkaline salt in crystals, is not worth more than five tons of the same salt, when freed from its water of crystallization. Kelp ashes appear, from these experiments, not to contain above five tons of the alkaline salt here spoken of in thirty tons of the ashes.

I took the 22 ounces of saline matter which I had procured from 30 ounces of dried barilla, and dissolving them in water obtained 36 ounces of fine crystals of alkali, and about 3 ounces of a salt which would not cry-

stallize, and which was in part sea salt. It appears from this experiment, compared with the preceding, that the salt procurable from barilla, contains a far greater proportion of pure alkali, than that from kelp does; and hence barilla is preferable to kelp, not only from its containing more saline matter in a definite weight, but from that saline matter being of a purer quality. The crystalline salt thus obtained, being exposed to the fire, was quickly melted, and when all the water which had entered into the composition of the crystals had been evaporated, the salt weighed $21\frac{1}{2}$ ounces, half an ounce having been lost by the operation.

The alkaline salt contained in the ashes of maritime plants, when exposed to the heat of a glass-house furnace,

furnace, loses considerably of its weight, but in moderate fires it loses nothing; hence this salt is called a *fixed alkali*. A pound of common salt contains about half a pound of this fixed alkali. Common salt is reckoned a mineral, there being large mines of it in most parts of the world. This fixed alkali, which constitutes near half the weight of common salt, and from the decomposition of which it is most probably produced, is therefore often called the *mineral, fossile, or marine fixed alkali*. It is entitled also to the name of the mineral fixed alkali, from its being met with in some mineral waters, and from its being found either ready formed upon the surface of the earth, or dug out of certain lakes, which are dried up in the summer, in

VOL. I. I Egypt,

Egypt, and other parts of the East. It is there called *natron*, and is supposed to be the nitre spoken of by Solomon, when he compares the effect which unseasonable mirth has upon a man in affliction, to the action of vinegar upon nitre ; * “ as vinegar upon nitre, so is he that singeth songs to a heavy heart : ” for vinegar has no effect upon what we call nitre ; but upon the alkali in question it has a great effect, making it rise up in bubbles with much effervescence. This alkali has been met with also on the Pic of Teneriffe and in Barbary, so that it is upon many accounts properly enough denominated the *mineral fixed alkali*.

The ashes of most other vegetables, as well as those of maritime plants, yield a salt which has many pro-

* Prov. xxv. 20.

properties in common with the mineral fixed alkali; but not having all the properties of that salt, it has for the sake of perspicuity been called the *vegetable fixed alkali*. Both the mineral and the vegetable fixed alkali are prepared by boiling the ashes, to extract the salt from the earth; the water containing the salt in solution, is then evaporated so as to leave the salt dry. From this manner of preparing them, these salts have been often called *lixivial* salts, *lix* and *lixivium* both signifying a ley made with ashes. The operation of evaporating the water is performed in large iron or copper pots; and from this circumstance these alkaline salts, especially the vegetable fixed alkali, have come under the name of *pot-ash*.

Great piles of wood are, in many countries, burnt for the express purpose of obtaining pot-ash. From the following experiments, some notion may be formed of the large quantities of wood which must be burned, in order to obtain even a small portion of pot-ash.

I desired a friend in Essex, who had plenty of dry oak billets, to ascertain the quantity of ashes which a certain weight of the wood would yield. He made the experiment with every possible precaution, and from 106 pounds, avoirdupois weight, of dry peeled oak, he obtained 19 ounces of ashes. I treated these ashes after the same manner in which I had endeavoured to ascertain the proportion of earth and saline matter in barilla, and kelp ashes; and from the

19 ounces obtained rather more than one ounce and a quarter of saline matter. From several repetitions of the experiment with ashes of the same kind it may be concluded, that 15 ounces of these ashes contained 14 ounces of earth, not soluble in water, and 1 ounce of saline matter : from this proportion it may easily be collected, that above 1300 tons of dry oak, and probably above 1800 tons of green oak, must be burned in order to obtain one ton of pot-ash.

The makers of pot-ash generally buy the wood ashes by the bushel, and sell the pot-ash by the ton ; but as the ashes of different woods, and indeed of different parts of the same wood, probably contain very different portions of saline matter ; it can-

not be expected that we should have any very uniform accounts of the number of bushels of ashes requisite to make a ton of pot-ash. Some dealers in this article are of opinion, that a ton of pot-ash may be procured from 400 bushels of ashes; others, from 450; others, from 560 of the best ashes; and others, lastly, from 700 bushels, at a medium, of good and bad ashes*. I find that a bushel of the dry ashes which are sold by the country people who burn wood to our soap-makers in Cambridge, weighs at a medium 58 pounds: hence, supposing every 15 pounds of such ashes to contain 1 pound of saline matter, it will follow, that 580 bushels of such ashes would

* Lewis's Experiments on American Pot-ash, p. 6.

would give 1 ton of saline matter. This correspondence with the accounts given by the pot-ash makers, confirms the analysis of the oak ashes before mentioned.

Under the direction and patronage of the Society for the Encouragement of Arts, Manufactures, and Commerce, large quantities of pot-ash have been made in America since the year 1763; and it would be a great saving to the nation, if it could be made in sufficient quantities in any part of the dominions of Great-Britain, since we are reckoned to pay to Russia, and other foreign states, not less than one hundred and fifty thousand pounds a-year for pot-ash *. We have inexhaustible

* Doffie's Mem. of Agricul. Vol. I. p. 248.

haustible mines of rock salt in this country, which the proprietors can afford at 10 shillings a-ton. A ton of rock salt, as has been before observed of common salt, contains about half a ton of mineral alkali, which is for most purposes far preferable to pot-ash. If a method could be contrived of extracting this alkaline part from rock salt, it would be a most serviceable discovery. To those who have leisure to attempt it, I would give the following hint—Whether the alkaline part of rock salt may not be obtained by calcining it in conjunction with charcoal in open fires? My reason for this conjecture is founded on the following experiment; Upon burning sea wrack to a black coal, and stopping the process at that point,

I have

I have obtained great plenty of common salt, but no mineral alkali from the black ashes; though we are certain, that when the black ashes are thoroughly calcined, or reduced to white ashes, mineral alkali may be obtained from them. This makes it probable, that the common salt contained in the black ashes of sea wrack, is decomposed, and changed into a mineral alkali, during the burning of the black ashes. There are reasons to suppose that the cinder of pit-coal would answer the purpose better than charcoal. But to return.

Tartar is a vegetable production, which forms itself on the sides of casks in which new wine is put; it is of a solid consistency, and is thence called by the Germans, wine-stone, (wyne-

(wyne-stein): this substance, when burned to ashes, yields a very pure vegetable fixed alkali, called, *salt of tartar*.

The reader is desired to distinguish between *cream of tartar* and *salt of tartar*; they are both salts, but not of the same class. Cream of tartar is an *acid*, and is prepared from tartar by dissolving it in water, and crystallizing the solution. Salt of tartar is an *alkali*, and is prepared from tartar by burning it, the acid being probably changed into an alkali by the fire.

Salt of tartar, as well as all other vegetable fixed alkalies when pure (for when purified they are all the same), attracts very strongly the humidity of the air, and thereby melts as it were into a liquor, which from
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its being procured in this singular way, and from its having also an unctuous appearance, tho' it has no other property of an oil, has been called *Oil of tartar per deliquium*. If you spread a little salt of tartar, or even common pot-ash on a plate, and expose it to the air in a cellar or other moist place for a few days, you will see the whole of it almost melted away into a thick transparent liquor, weighing near four times as much as the weight of the salt you exposed. The mineral fixed alkali, exposed in the same way, will not be changed into a fluid; and this is one mark by which the mineral and vegetable fixed alkalies may be distinguished from each other. Both of these fixed alkalies change the blue colour of syrop of violets into a green,
and

and by this property they are distinguishable from acids, which give a red colour, as well as by their taste, which is caustic and fiery, every way very different from a sour taste. They bubble up also or effervesce when mixed with acids, as may be seen by mixing lemon-juice and salt of tartar together. This effervescence proceeds from the discharge of an elastic fluid, called *fixed air*, but it cannot be said to be characteristic of alkalies; since chalk, marble, limestone, and other earths and stones not soluble in water, contain a large portion of *fixed air*, and, when mixed with acids, effervesce as much as fixed alkalies. From this property, these earthy and stony substances have, in many systems of mineralogy, been called *alkaline* earths and stones.

Besides

Besides the fixed alkaline salts separable from the ashes of maritime plants, and other vegetable substances, there is another species of salt separable chiefly from animal substances, as from urine, horns, bones, &c. by distillation. This salt effervesces with acids, and gives a green colour to vegetable blues, and it is from hence called an alkali; but being easily dissipated in a small degree of heat, it is called a *volatile alkali*. By this great volatility it is sufficiently distinguished from the two fixed alkalies, as well as by the pungency of its smell; fixed alkalies, when pure, having no smell.

Of

Of neutral salts.

Neutral salts are distinguished both from acids and alkalies by their taste, which is neither sour nor caustic, by their not effervescing with acids, by their not producing any change in the colour of syrop of violets. Of this kind are common salt, Glauber's salt, salt-petre, and a great variety of others. Any acid, when united with any alkali in such proportion that the compound does not possess any of the characteristic properties of either of its component parts, is a neutral salt. The term neutral, was first applied to a salt formed by an union of an acid and an alkali; but it has now a more extensive signification, denoting the salt formed by

the union of an acid with any alkali, earth, or metallic substance. The substance with which the acid unites itself in the formation of a neutral salt, is often called the *basis* of that salt.

The following tables of salts will help to fix in the reader's mind the general division of saline substances, especially if he will be at the trouble to familiarize himself to the names, by procuring from his drug-gift specimens of the several kinds.

A Table

A Table of Salts in general.

Salts.		
Neutral	Alkaline	Acid
<p>From the Union of any Acid with any</p> <p>Alkali Earth Metallic Substance</p>	<p>Fixed</p> <p>Mineral—Fossil—Marine—Native Vegetable—Psalsh—Salt of Tartar—Salt of Wormwood Obtained by Distillation from putrid Blood, Urine, Bones, Horns and other animal Substances; and also from Wormwood and many other, both Vegetables and Minerals, when distilled with a violent Fire.</p>	<p>Mineral</p> <p>Vitriolic Acid—Spirit of Vitriol—Oil of Vitriol Nitrous Acid—Aqua Fortis—Glauber's fuming Acid of Nitre Marine Acid—Muriatic Acid—Glauber's fuming Acid of Salt Native Juices of Lemons and other Acid Vegetables</p> <p>Vegetable</p> <p>Facitious by Fermentation Diffillation Acetous Acid, or Vinegar Tartareous Acid, or Tartar Not specifically known</p> <p>Animal</p> <p>Phosphoric Acid From Ants, Butter, &c. by Distillation</p>

A Table of neutral Salts, with Alkaline Bases.

Acid.		
Vitriolic with	{ Mineral Vegetable Volatile }	{ Alkali makes Glauber's Salt Vitriolated Tartar Vitriolic Sal Ammoniac }
Nitrous with	{ Mineral Vegetable Volatile }	{ Alkali makes Cubic Nitre Common Nitre or Saltpetre Ammoniac Nitre }
Marine with	{ Mineral Vegetable Volatile }	{ Alkali makes Common Salt Digestive Salt of Sylvius Common Sal Ammoniac }
Acetous with	{ Mineral Vegetable Volatile }	{ Alkali makes A crySTALLIZABLE Salt, not yet named Diuretic Salt, improperly called Terra fol. Tar. Spirit of Mindererus }
Tartareous with	{ Mineral Vegetable Volatile }	{ Alkali makes Rochelle Salt Soluble Tartar Soluble Ammoniac Tartar }

* In this general account, I purposely omit the mention of the lately discovered Sparry Acid; of the Acid of Amber; of the Acid of Benjamin, and other Bitumens; and of some other particularities relative to this subject.

It may not be improper, in this place, to mention two propositions much insisted on by chemical writers of the greatest eminence, but which appear to be founded rather on probable conjecture than certain experiment. The first is, that the *vitriolic acid* is the only saline principle in nature, all other acids and alkalies being nothing but combinations of this *universal acid* with earth, air, oil, and water, in different proportions. The second is, that the *vitriolic acid* itself is a compound body, formed from an intimate union of *earth* and *water*. The possibility of the truth of the first proposition, which asserts, that one substance may be so combined with several others as to constitute a great variety of different compounds, may be illustrated

illustrated from what we know of water; which is the chief constituent part of bodies in appearance very different from each other, as of blood, urine, milk, wine, wood, coal, &c. yet the *marine acid* seems to be as abundantly diffused over the earth as the vitriolic; and cannot, I think, be said to be derived from it. As to the second proposition, though we should grant that nothing but earth and water can be procured from the analysis of any salt, (which, considering the loss sustained almost in every analysis from the escape of some elastic fluid which cannot be condensed, cannot readily be admitted;) yet as no one could ever form a saline substance by uniting earth and water together, we may fairly doubt concerning its

truth : this doubt, however, is not to be understood as a denial. The sum of the matter is this : earth and water cannot be formed by us into saline substances : nature *may* have different modes of combining them, so as to produce the effect ; or nature *may*, in producing the effect, make use of a third or a fourth principle. It must be left to future experience to simplify our knowledge concerning saline substances, as well as concerning those fluids which produce magnetism and electricity, and all the various phenomena attending mineral exhalations.

ESSAY

E S S A Y IV.

Of Fire, Sulphur, and Phlogiston.

FIRE is so subtile an agent in nature, that we can reason little concerning it, except from experiment; and we are even at a loss from thence to determine, in many cases, either its absolute quantity or real presence. If, with the generality of philosophers, we assume heat as its characteristic property, and define fire to be that which warms or heats bodies, we cannot avoid seeing at once, the ambiguity of this criterion: it is as precarious as the perceptions of different men

at the same time, or of the same man at different times, in summer and in winter, in a fever and in health. The light of the moon, when collected into the focus of a large burning-glass, is found to be about one thousand times less dense than the direct rays of the sun: hence it is, that it excites no motion in the mercury of the most sensible thermometer. But from the brightness of the image in the focus, as well as from the luminous appearance of rotten wood, putrid fish, and other phosphorescent bodies, some philosophers have inferred, that wherever there is light there is fire: but as the converse of this proposition is not true, since fire often exists in large quantities, as in boiling fluids, in metals moderately heated,

heated, &c. without light; this cannot be a distinguishing mark of the presence of fire. The dilatation which fire occasions in all bodies, whether solid or fluid, hard or soft, light or heavy, may be esteemed the most certain proof of its presence and agency. This property serves admirably to mark its degrees and minute variations within certain limits, but not to ascertain either its presence or its quantity in extreme cases, unless we know the real magnitudes of bodies totally destitute of it. However, admitting this phenomenon as the most certain indication of the existence of fire, it may be accounted for in the following manner.

From the 14th section of Sir *Isaac Newton's Principia*, we learn, that

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the motions of small bodies, when attracted perpendicularly towards any surface, according to any law, are similar to the motions of the rays of light, with respect to the fundamental properties of Inflection, Reflection, and Refraction : from hence chiefly, as well as from other arguments, we infer, that rays of light are small corpuscles, emitted from shining bodies, and moving with uniform velocities in uniform mediums; but with variable velocities in mediums of variable densities. This being admitted, it will follow, that in whatever quantity the rays of light are made to move in a medium of an uniform density, they will not agitate the particles, or produce any augmentation of bulk in that medium. If the atmosphere

sphere was reduced to a medium of an uniform density, surrounding the earth every where to the height of five miles, it would be expanded in bulk, or warmed only as its outward and inward surface. The sun's rays, by coming out of a *vacuum* into a denser medium, would be attracted by the particles composing that medium; and, since all attraction is mutual, they would excite a motion, an expansion, an heat, at the outward surface where they entered: from thence they would proceed uniformly, without producing any effect, till they came to the inward surface of the atmosphere contiguous to the surface of the earth, where they would undergo another acceleration of velocity, and would excite another degree of motion,
another

another degree of expansion or heat. Such an atmosphere would be the coldest in the middle, the heat decreasing from each surface. We may, perhaps, from what has been said, conceive, in some measure, how bodies are expanded, heated, and volatilized, by the agency of the particles of light. These particles act upon the minute constituent parts of bodies, not by impact, but at some indefinitely small distance; they attract, and are attracted; and in being reflected, or refracted, they excite a vibratory motion in the component particles. This motion increases the distance between the particles; an increase of the distance between the constituent parts of any body, is an augmentation of bulk, an expansion in every dimension,

sion,—the most certain characteristic of fire. This expansion, which is the beginning of a disunion of the parts, being increased by the increasing magnitude of the vibrations proceeding from the continued agency of the light, it may easily be apprehended, that the particles will at length vibrate beyond their sphere of mutual attraction, and thus the texture of the body will be altered or destroyed : from solid it may become fluid, as in melted gold ; or from being fluid, it may be dispersed in vapour, as in boiling water.

According to this theory, we must infer, that the constituent parts of all bodies are in perpetual motion. The temperature of the atmosphere is different in different latitudes, and
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it changes, almost every instant, in the same. The temperature of bodies is ever proportionable to that of the surrounding atmosphere, and from thence it must be perpetually varying. The bulk of every body is proportionable to its temperature, and must therefore be subject to a perpetual vicissitude. Now the body will be in an expanded, in the next instant, its heat happening to be diminished, it will be in a contracted state; which variation of dimensions cannot be effected without a perpetual vibratory motion of its constituent parts.

It being established then, that the rays of the sun, even in their most condensed state, as in the focus of a burning speculum, do not otherwise produce heat than as they excite a

motion more or less violent amongst the constituent parts of bodies ; and the effects of culinary fire, of that produced by friction, or by the impact of hard bodies, being similar to those produced by the agency of the sun's light, it may be conjectured, that they are produced after a similar manner ; and that fire is nothing distinct from the parts of bodies put into motion by various causes, as the impulse of light, friction, percussion, putrefaction, attraction of cohesion, &c. and consequently that it may be mechanically produced, altered, or destroyed in all bodies, with greater or less facility, according as the parts of the body are more or less disposed for motion.

This conclusion seems to be consonant

sonant with the principles of the received philosophy. Newton in his 5th quære annexed to his Optics, asks, Do not bodies and light act mutually upon one another? that is to say, bodies upon light in emitting, reflecting, refracting, and inflecting it; light upon bodies for heating them, and putting their parts into a vibratory motion, wherein heat consists?

There are various other opinions concerning the nature of fire and its method of action, which, though different from what has been offered, are not less probable: I will content myself with mentioning two more.

Boerhaave thinks that fire is a fluid of a nature peculiar to itself; that it was created such as it is, and

cannot be altered in its nature or properties, destroyed or produced; that it naturally exists in equal quantities in all places; that it is wholly imperceptible to our senses, and only discoverable by such effects as it produces, when, by various causes, it is for a time collected into a less space than what, from its tendency to an universal and equable diffusion, it would otherwise occupy. All the bodies which are situated in the immensity of space, may, according to this opinion, be divided into fire expanding all other bodies, and into all the other bodies which are not fire, but resist its action. The matter of this fire is not supposed to be derived from the sun in any wise; the solar rays, whether direct or reflected, are of use only as they impel the particles
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of fire in parallel directions : that parallelism being destroyed, by intercepting the solar rays, the fire instantly resumes its natural state of uniform diffusion*. Consistent with this explication, which attributes heat to the matter of fire, when driven in parallel directions, a much greater

* Possent omnia corpora locata in spatio immenso dividi, in ignem expandentem omnia reliqua corpora, et in cætera universa corpora quæ non sunt ignis — Ignem illum semper esse ubique præsentem, tam in pleno corporeo plenissimo quam in vacuo inanissimo — Ignem hunc æquabilissime distribuitamdiu, quamdiu non nascitur causa singularis in loco certo ignem hunc dispersum colligens — Ignem hunc non esse a sole, quoad materiam ullo modo — Vim ignis a sole determinatam in rectas parallelas remanere in omni tempore, quo emanatio vel reflexio durat — intercepta rectitudine radiorum a sole, ignem in parallelismum agentium, illico cessat ille parallelismus, atque statim illo ipso momento ignis partes expanduntur æquabiliter quaquaversum. — Boerh. Chem. Vol. 1.

greater must be given it, when the quantity so collected, is amassed into a focus; and yet the focus of the largest speculum does not heat the air, or medium in which it is formed, but only bodies of densities different from that medium.

The author of the *Lettres Physiques* is of opinion, that the solar rays are the principal cause of heat; but that they only heat such bodies as do not allow them a free passage*. In this remark he is agreed with Newton †; but then he differs totally from him, as well as from Boerhaave, concerning the nature of the

* Les rayons du soleil n'échauffent les corps qu'entant que les corps ne leur accordent un libre passage à travers. Lett. Phys.

† Radii solis non agitant media quæ permanant, nisi in réflexionne et refractione. New.

the rays of the sun. He does not admit the emanation of any luminous corpuscles from the sun, or other self-shining substances, but supposes all space to be filled with an æther of great elasticity and small density, and that light consists in the vibrations of this æther, as sound consists in the vibrations of the air; the particles of the one medium exciting, by impulse upon the organ of vision, the idea we call light; the particles of the other medium exciting, by impulse on the organ of hearing, the idea we call sound*. But as a bell will not of itself begin those

* La lumière n'est autre chose qu'une agitation ou ébranlement causé dans les particules de l'ether qui se trouve partout. — Il n'y a donc rien qui vienne actuellement du soleil jusque à nous. Let. Phy.

those vibrations by which the air is put in motion, nor continue with equal intensity the vibrations, when once excited, without the concurrence of some mechanical cause ; so neither will the sun either begin or continue his vibrations, by which the supposed æther is put in motion, without a similar mechanical agency. In ascending from effects to causes we must ever arrive, upon whatever hypothesis we proceed, at some first cause, which does not admit an explanation from mechanical principles : this is evidently the case in the present inquiry. Upon Newton's supposition, the cause by which the particles of light, and the corpuscles constituting other bodies, are mutually attracted and repelled, is uncertain. The reason of the uniform

diffusion of fire, of its vibration, and repercussion, as stated in Boerhaave's opinion, is equally inexplicable; and in the last mentioned hypothesis, we may add to the other difficulties attending the supposition of an universal æther, the want of a first mover to make the sun vibrate. These are the opinions most worthy of notice, concerning elementary fire; and of these it may be said, as Cicero remarked of the opinions of philosophers concerning the nature of the soul, — *harum sententiarum quæ vera sit, Deus aliquis viderit, quæ verisimillima, magna questio est* *.

But

* The reader who is desirous of making a deeper inquiry into this matter, may consult a very ingenious tract entitled, Experiments and Observations on animal Heat, and the Inflammation of combustible Bodies, by Dr. Crawford;

But besides this *elementary fire*, which chemists conceive to be every where uniformly diffused, they are of opinion that fire enters, in different proportions, into the composition of all vegetables and animals, and most minerals; and in that condensed, compacted, fixed state, it has been

Crawford; and Mr. Scheele's Experiments on Air and Fire, translated from the German by Dr. Forster, and illustrated with judicious notes by Mr. Kirwan; and a late work of Wallerius', entitled *Meditationes de Orig. Mund.*

May not the common degree of *heat* which arises from the mixture of different quantities of the same fluid heated to different degrees, be investigated by the same rule, by which the common *velocity* of hard or non-elastic bodies after their impact in the same direction is calculated, putting the *momentum* of heat to be equal to its degree multiplied into the quantity of heated matter?

been denominated the *phlogiston*. Of itself, in its natural state of uncombined expansion, fire is not esteemed capable of shining, or burning; when chemically conjoined with the other principles of bodies, it is that alone which conceives and continues those motions by which bodies are made to shine, to burn, to consume away. All bodies are more or less susceptible of combustion, according to the quantity of this principle which enters into their composition, or the degree of force with which it adheres to them. In the act of burning, and it may very probably be during the fermentation, and putrefaction, and chemical solutions of various bodies, it recovers its fluidity, is expanded and dispersed into the air, or combined anew with such substances

substances as it has an attraction to. Notwithstanding all that perhaps can be said upon the subject, I am sensible the reader will be still ready to ask—*what is phlogiston?* You do not surely expect that chemistry should be able to present you with a handful of phlogiston, separated from an inflammable body; you may just as reasonably demand a handful of magnetism, gravity, or electricity to be extracted from a magnetic, weighty, or electric body. There are powers in nature which cannot otherwise become the objects of sense, than by the effects they produce; and of this kind is phlogiston. But the following experiments will tend to render this perplexed subject somewhat more clear.

If you take a piece of *sulphur*,

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and set it on fire, it will burn intirely away, without leaving any ashes, or yielding any foot. During the burning of the sulphur, a copious vapour, powerfully affecting the organs of sight and smell, and the action of the lungs, is dispersed. Means have been invented for collecting this vapour, and it is found to be a very strong acid. The acid thus procured from the burning of sulphur, is incapable of being either burned by itself, or of contributing towards the support of fire in other bodies : the sulphur from which it was procured was capable of both : there is a remarkable difference then, between the acid procured from the sulphur, and the sulphur itself. The acid cannot be the only constituent part of sulphur ; it is evident that

something else must have entered into its composition, by which it was rendered capable of combustion. This *something* is, from its most remarkable property, that of rendering a body combustible, properly enough denominated the food of fire, the *inflammable principle*, the *phlogiston*.

From this analysis we may conclude, that the constituent parts of *sulphur* are two; — an *inflammable principle*, which is dispersed in the act of combustion, and an *acid*. The proportion of these parts has been ascertained; and it is found, that in any mass of sulphur, the weight of the inflammable principle is to that of the acid in the proportion of 3 to 50 *.

If

* The experiment from which this proportion is derived, is said to have been made by

If you burn *charcoal* in the open air, and hold a glass over its flame, you will perceive that it burns without emitting either any watery vapour or sooty impurity; and nothing will remain, from a large portion of charcoal, but a small portion of white ashes, which are incapable of any further combustion. The principle effecting the combustion of the charcoal, and dispersed by the act of combustion, is the phlogiston.

If you set *spirits of wine* on fire, they will, if pure, burn intirely away: they differ from charcoal in this,

by M. Brandt with great accuracy about the year 1756. Spielm Chem. p. 111. and Chem. Dict.—Newman from a similar experiment infers, that in 16 ounces of sulphur, there are upwards of $15\frac{3}{4}$ ounces of pure acid, and not quite $\frac{1}{4}$ of an ounce of the inflammable principle. Newm. Chem. p. 163

this, that they emit a vapour; but they leave no residuum. You may by proper vessels collect the vapour of burning spirits, and you will find it to be an insipid water, incapable of combustion. The principle effecting the combustion of the spirits of wine, and dispersed by the act of combustion, is the phlogiston.

Some *metallic substances* burn, when sufficiently heated, with a flame more bright than that of spirits of wine, or charcoal; others burn or smother away like rotten wood; and most of them, when they have been kept in the open air in a proper degree of heat, lose their metallic appearance, and are converted into earth. Thus *red lead* is the earth procured from the burning of lead; and *putty*, such as the polishers of glass and marble

marble use, is the earth procured from tin. The principle effecting the combustion of metallic substances, and dispersed in the act of combustion, is the phlogiston.

The *acid of the sulphur* ; the *ashes of the charcoal* ; the *water of the spirits of wine* ; the *earths of metallic substances*, are utterly incapable of combustion : their respective differences from sulphur, charcoal, spirits of wine, and metallic substances, with respect not only to inflammability, but to smell, colour, consistency, and other properties, are attributed to the phlogiston which is dispersed during the combustion of each of them.

This inflammable principle, or phlogiston, is not one thing in animals, another in vegetables, another in

in minerals, it is absolutely the same in them all; just as water which enters into the composition of flesh, wood, coal, is still water, though its existence and homogeneity be rendered more doubtful in some substances than in others. This identity of phlogiston may be proved from a variety of decisive experiments; I will select a few, which may at the same time confirm what has been advanced concerning the constituent parts of sulphur.

From the analysis or decomposition of sulphur effected by burning, we have concluded, that the constituent parts of sulphur are two, — an *acid* which may be collected, and an *inflammable principle* which is dispersed. If the reader has yet acquired any real taste for chemical truths,
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he will wish to see this analysis confirmed by synthesis ; that is, in common language, he will wish to see sulphur actually made, by combining its acid with an inflammable principle. It seldom happens that chemists can reproduce the original bodies, though they combine together all the principles into which they have analysed them ; because not only the number and proportions of the principles, but the order also of their arrangement must be observed, before that can be effected : in the instance, however, before us, the reproduction of the original substance will be found complete.

As the inflammable principle cannot be obtained in a palpable form separate from all other bodies, the only method by which we can attempt

tempt to unite it with the acid of sulphur, must be by presenting to that acid some substance in which it is contained. Charcoal is such a substance, and by distilling powdered charcoal and the acid of sulphur together, we can procure a true yellow sulphur, in no wise to be distinguished from common sulphur. This sulphur is formed from the union of the acid with the phlogiston of the charcoal; and the charcoal may by this means be so entirely robbed of its phlogiston, that it will be reduced to ashes, as if it had been burned. Animal substances reduced to the state of a black coal, will, by being treated in the same way, yield sulphur.

Spirits of wine, we have said, consist of phlogiston united with water; and

and if we distil a mixture of spirits of wine and the acid of sulphur, we shall towards the end of the operation obtain a pure sulphur.

Oil of turpentine is very inflammable, and consequently abounds with the principle which has been denominated phlogiston; and from a distillation of acid of sulphur with oil of turpentine, a sulphur may be procured.

But one of the shortest and most obvious ways of illustrating both the composition of sulphur and the phlogiston of metallic substances, is the following.—Upon melted lead pour the acid of sulphur; collect the vapour which will arise, by holding a very large glass or other vessel over the melted lead, and you will, as soon as the vapour is condensed, observe
several

several filaments of sulphur sticking to the sides of the glass.—When lead is in a state of strong fusion, its phlogiston is in a state of dispersion; the acid of sulphur instantaneously unites itself with this phlogiston, and forms sulphur. It is probable, that sulphur might be procured by the same means from a variety of other bodies, when in a state of actual combustion.

I will in this place, by way of further illustration of the term phlogiston, add a word or two concerning the necessity of its union with a metallic earth, in order to constitute a metal.

Lead, it has been observed, when melted in a strong fire, burns away like rotten wood; all its properties as a metal are destroyed, and it is

reduced to ashes. If you expose the ashes of lead to a strong fire, they will melt; but the melted substance will not be a *metal*; it will be a yellow or orange-coloured *glass*. If you pound this glass and mix it with charcoal dust, or if you mix the ashes of the lead with charcoal dust, and expose either mixture to a melting heat, you will obtain, not a *glass*, but a *metal*, in weight, colour, consistency, and every other property the same as lead. This operation by which a metallic earth is restored to its metallic form, is called *Reduction*. The ashes of lead melted *without* charcoal become *glass*; the ashes of lead melted *with* charcoal become a *metal*; the charcoal then must have communicated *something* to the ashes of lead, by which they are changed from

from a glass to a metal. Charcoal consists but of two things, of ashes, and of *phlogiston*; the *ashes* of charcoal, though united with the ashes of lead; would only produce glass; it must therefore be the other constituent part of charcoal, or *phlogiston*, which is communicated to the ashes of lead, and by an union with which the ashes are restored to their metallic form. The ashes of lead can never be reduced to their metallic form, without their being united with some matter containing *phlogiston*; and they may be reduced to their metallic form, by being united with *any* substance containing *phlogiston* in a proper state, whether that substance be derived from the animal, vegetable, or mineral kingdom; (for tallow or iron filings may be

substituted with success in the room of charcoal, in the experiment of reducing the ashes of lead) and thence we conclude, not only that phlogiston is a necessary part of a metal, but that phlogiston has an identity belonging to it, from whatever substance in nature it be extracted. And this assertion still becomes more general, if we may believe that metallic ashes have been reduced to their metallic form, both by the solar rays and the electrical fire.

E S S A Y V.

*Of the Origin of Subterraneous
Fires.*

THE most remarkable changes which have taken place in the form and constitution of the earth, since the deluge, have probably been produced by subterraneous fires ; for it is to their agency that philosophers ascribe volcanos and earthquakes ; those tremendous instruments of nature, by which she converts plains into mountains, the ocean into islands, and dry land into stagnant pools.

Dr. Hooke formerly had maintained that all land had been raised out of the sea by earthquakes; and modern philosophers seem to admit his hypothesis, though not, perhaps, in its utmost latitude. Thus one of them is of opinion, that *Iceland*, which is bigger than *Ireland*, has been produced by volcanos in the course of several centuries*. Another, after giving an ingenious conjecture concerning the origin of all the *tropical low isles* in the South Sea, assures us, that of the *higher isles* there is hardly one of them which has not strong vestiges of its having undergone some violent alteration by a volcano. Some of them have volcanos still subsisting; others, amongst

* See Letters on *Iceland* by Dr. Uno Von Troil, p. 222.

amongst which are *O-Takeitee* and *Huabeine*, seem to have been elevated, in remote ages, from the bottom of the sea by subterraneous fires *.

When these fires were first kindled ; by what sort of fuel they are still maintained ; at what depths below the surface of the earth they are placed ; whether they have a mutual communication ; of what dimensions they consist ; and how long they may continue, are questions which do not admit an easy decision. The surface of the earth is admirably fitted for the support of the existence and well-being of all the animals which

M 4 inhabit

* Observations made during a Voyage round the World by Dr. Forster, p. 151 ; where the reader will find in a note, a learned reference to the works of a great many authors, on the subject of isles raised out of the sea by the action of a subterraneous fire.

inhabit it. God has given *us* the ability also to penetrate a very little below this surface; and as the reward of our industry, he has placed within our reach a great variety of useful minerals; but as to the central recesses of the globe, we can never penetrate into them. A gnat essaying the feeble efforts of its slender proboscis against the hide of an elephant, and attempting thereby to investigate the internal formation of the body of that huge animal, is no unapt representation of man attempting to explore the internal structure of the earth, by digging little holes upon its surface.

But though it will ever be impossible for us to search far into the bowels of the earth, or to imitate, in an extensive degree, the great operations

rations which are constantly carrying on beneath its surface, yet it affords a curious mind no mean degree of satisfaction to be able, by obvious experiments, to form some reasonable conjectures concerning them.

Mr. Lemery *, as far as I have been able to learn, was the first person who illustrated, by actual experiment, the origin of subterraneous fires. He mixed twenty-five pounds of *powdered sulphur* with an equal weight of *iron filings*; and having kneaded the mixture together, by means of a little *water*, into the consistence of a paste, he put it into an iron pot, covered it with a cloth, and buried the whole a foot under ground.

* Cours de Chemie, p. 176. & Mem. de l' Acad. des Scien. a Paris, Ann. 1700.

ground. In about eight or nine hours time the earth swelled, grew warm, and cracked; hot sulphureous vapours were perceived; a flame which dilated the cracks was observed; the superincumbent earth was covered with a yellow and black powder: in short, a subterraneous fire, producing a volcano in miniature, was spontaneously lighted up from the reciprocal actions of sulphur, iron, and water.

That part of this experiment which relates to the production of fire, by the fermentation of iron filings and sulphur when made into a paste*, has been frequently repeated

* The words *ferment* and *fermentation* may perhaps be improperly applied to the spontaneous transposition of parts, which takes place in *mineral substances*; but the reader cannot fail to understand what is meant by them when thus applied.

peated since the time of Mr. Lermery. I myself have made it more than once, but I have nothing material to add to his account, except that the flame, when the experiment is made in the open air, is of very short duration; and that the whole mass, after the extinction of the flame, continues at intervals, for a longer or shorter time, according to its quantity, to throw out sparks; and that a ladle full of the ignited mass, being dropped down from a considerable height, descends like a shower of red-hot ashes, much resembling the paintings of the eruptions of Mount Vesuvius which may be seen at the British Museum. It has been observed, that large quantities of the materials are not requisite to make the experiment succeed, provided

vided there be a due proportion of water : half a pound of steel filings, half a pound of flowers of brimstone, and fourteen ounces of water, will, when well mixed, acquire heat enough to make the mass take fire *.

That heat and fire should be generated from the spontaneous actions of *minerals* upon each other, is a phenomenon by no means singular in nature, how difficult soever it may be to account for it. The heat of putrescent dunghills, of the fermenting juices of vegetables, and, above all, the spontaneous firing of hay not properly dried, are obvious proofs that *vegetables* possess this property as well as minerals. In both vegetables and minerals, a definite

* Sage Miner. Vol. I. p. 42.

finite quantity of moisture is requisite to enable them to commence that intestine motion of their parts, which is necessary for the production of fire. Iron and sulphur would remain mixed together for ages without taking fire, if they were either kept perfectly free from moisture, or drenched with too much water; and vegetables in like manner, which are quite dry, or exceedingly wet, are incapable of taking fire whilst they continue in that state*.

But

* *Animal* substances when laid on heaps, have been observed to take fire. “ M. Montet rapporte dans l’histoire de l’Académie Royale des Sciences, année 1776, que des petites étoffes appellés *imperiales*, gardées en tas, prirent feu d’elles-mêmes.” Instruc. sur l’usage de la Houille par M. Venel. It is not improbable that filings of copper and other

But though it is certain from the experiment, that mixtures of iron and sulphur, when moistened with a proper quantity of water, will spontaneously take fire; yet the origin of subterraneous fires cannot, with any great degree of probability, be referred to the same principle, unless it can be shewn that nature has combined together in large quantities iron and sulphur, and distributed the composition through various internal parts of the earth.

Now that this is really the case we can have no doubt. There is, perhaps, no mineral more commonly met

other metals, when mixed in a due proportion with sulphur and water, would acquire a heat, and perhaps take fire, especially if the quantities were large; but experiments of this kind have not hitherto been made.

met with than that which is composed of iron and sulphur. It is found not only upon the surface of the earth, but at the greatest depths below it, to which mines have been hitherto driven; not only in England or Italy, Europe or Asia, but in all parts of the world. This mineral is called in some parts of England, *copperas-stone*; in others, *brazil*; in others, *brass-lumps*; in others, *rust-balls*; in others, *horse-gold*; in others, *marcasite*; though naturalists are now, I think, agreed to give that name to such mineral bodies as are angular and crystallized, especially into a cubical form. The scientific name is *Pyrites*,—*fiery*; a denomination expressive enough of the property which this mineral

mineral has of striking fire with steel, and of spontaneously taking fire, when laid in heaps, and moistened with water.

Sulphur and iron are the chief constituent parts of the pyrites; arsenic, however, is sometimes united with the iron instead of sulphur, and sometimes sulphur and arsenic are both of them combined with iron. The pyrites also, accidentally, contains copper, silver, and perhaps gold: hence the pyrites has been distinguished by mineralogists into various sorts, by attending, either to its internal constitution, as the iron, the copper, the sulphureous, the arsenical pyrites; or to its external figure, as the pyramidal, the cubical, the spherical, the prismatic pyrites;

or

or to its colour, as the grey, white, yellowish, yellow, orange pyrites *.

Though the reader may have never contemplated the various species of the pyrites in any cabinet of natural history, or taken notice of such kinds as are commonly to be met with in chalk-pits, in beds of clay, or upon the sea shore in many places of England, yet the yellowish matter, often adhering to, or mixed with the substance of pit-coal, cannot, surely, have escaped his observation: that matter consists of *sulphur* and *iron*, and is a species of the pyrites. So much

* Whoever wishes to become fully acquainted with the natural history of the pyrites, may consult the *Pyritologia* of Henckel, where he will find the origin, nature, and uses of this mineral investigated with the greatest learning and ingenuity.

much of this sort of the pyrites is dug up together with the coal, at Whitehaven, Newcastle, and other places, that people are employed to pick it out from amongst the coal, lest it should vitiate its quality, and render it less saleable. The pieces of the pyrites which are separated from the coal, are not thrown aside as useless, but laid in heaps, for a purpose to be mentioned hereafter; and these heaps, not many years since, *took fire* both at *Whitehaven* and in the neighbourhood of *Halifax*. The same accident was observed above a hundred years ago at *Puddle Wharf* in London, where heaps of coal which contained much of this pyrites *took fire* *.

Though Lemery was the first person

* Jorden of Miner. Wat. C. xiv.

person who, by artificial mixtures of sulphur and iron, produced fire, yet that natural mixtures of these substances would *spontaneously take fire*, was known before he made his experiment. Thus, to omit what is said by Pliny and the ancients, we are told by good authority, that one Wilfon at *Ealand* in *Yorkshire*, about the year 1664 or before, had piled up in a barn many cart-loads of the pyrites, or brass-lumps, as they were called by the colliers, for some secret purposes of his own: the roof of the barn happening to be bad, the pyrites were wetted by the rain; in this state they began to smoke, and presently *took fire*, and burned like red-hot coals *.

We have an account, in the Phi-

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* Power's Microf. Obser. p. 62.

losophical Transactions for 1693 †, of a covetous master of a copperas work at *Whitestable* in *Kent*, who, in order to break his neighbour's work, had engrossed all the pyrites or copperas-stone in the country : he built a shed over two or three hundred tons of these stones, to keep off the rain. In the space, however, of six or seven months, the mass (being probably wetted by the moisture of the atmosphere, or by the rain, which, notwithstanding the shed, might have fallen upon it) *took fire* and burned for a week ; it quite destroyed his shed, and disappointed all his hopes of profit ; for the pyrites was in part converted into a substance like melted metal, and in part it looked like red-hot stones : all the sulphur was

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consumed, and the neighbourhood was miserably afflicted by the noxious exhalation which it sent forth.

In the month of August 1751, the *Cliffs* near *Charmouth* in *Dorsetshire* took fire, in consequence of a heavy fall of rain after a hot and dry season, and they continued at intervals to emit flame for several years.—These *Cliffs* consist of a dark-coloured bituminous loam, in which are imbedded large quantities of different kinds of the pyrites. The same kind of flame has been frequently observed in the *Cornish* mines, and this mineral fire sometimes leads to the discovery of a mine; but wherever it is found to exist, the iron pyrites is generally discovered near it*.

There

* *Philos. Transf.* Vol. LII. p. 119.

There are some forts of earth from which alum is made, which abound so much with the pyrites, that the proprietors of the works are forced to keep them constantly well watered, in order to prevent their taking fire *.—But it would be useless to pursue this subject further; we have adduced proof sufficient, that nature furnishes materials, which, under certain circumstances, may become the occasion of subterraneous fires. The requisite circumstances are a proper quantity of the materials, a proper portion of water to moisten them, and, perhaps, a communication with the air may be necessary. A small quantity of the pyrites

* Waller. Min. Vol. I. 25. — Henckel Pyritol. p. 312. — Minera. par M. Val. de Bomare, Vol. I. p. 296.

rites is sufficient to kindle a fire; water is almost every where found in such great plenty below the surface of the earth, that it constitutes one of the greatest impediments to our sinking pits to any great depth; and air, if it should be thought absolutely necessary to the spontaneous firing of the pyrites, may be conceived either to accompany the water in its dripping, or to descend into the innermost parts of the earth through the fissures which are found upon its surface. When a subterraneous fire is once kindled, it may be supported for ages by other substances, as well as by those which first gave rise to it: thus, if a quantity of the pyrites should take fire in a stratum of coal, or of *shale*, or of any other substance strongly im-

pregnated with bitumen, the fire might continue till the stratum was consumed*.

There are such a great number of volcanos now subsisting in every quarter of the globe, and so many unequivocal vestiges of others, which in length of time have become extinct, that some philosophers think they have reason on their side in supposing either, that the earth, at some considerable distance below its surface, is surrounded with a stratum of ignited matter of

* There are some coaleries on fire now in Scotland, which were on fire in the time of Agricola.—Pennant's Tour in Scot. Part II. p. 201. See an account of the coaleries on fire in Staffordshire, in Dr. Plott's Nat. Hist. of that County; and of the substances sublimed from the burning coal-pits at Newcastle in Philos. Transf. for 1676.

of a definite thickness ; or that the whole central part of it is nothing but a mass of melted minerals, which every where struggling for vent, bursts forth where there is the least resistance, shivering into rude fragments the superincumbent crust of earth, and deluging with mountainous torrents of liquid fire the adjoining countries.

We do not know of what kind of materials the inward part of the earth is composed ; the water, coal, earths, stones, metals met with upon its surface, have, bulk for bulk, very different weights ; and a similar inequality of similar materials may take place at all depths below the surface. It has been gathered, however, from very ingenious observations and calculations, upon the

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attraction of the hill *Scheballein* in Scotland, that the mean density of the whole earth is about four times and a half the density of water, the mean density of stones, suppose Portland stone, being two times and a half the density of water*. Hence if this globe of earth could be weighed in a scale, it would require two equal globes and a half of Portland stone, or four equal globes and a half of water to balance it. The whole earth being so much heavier, bulk for bulk, than the general matter near its surface, it has been conjectured, that there must be somewhere within the earth, towards the more central parts, great quantities of metals, or such like dense matter, to counterbalance the

* *Philos. Trans.* 1778. p. 784.

the lightness of the superficial materials, so as to make up the whole weight of the earth. Supposing the diameter of the earth to be 7920 miles, and that it was composed of an inward globe 5110 miles in diameter, and of an outward spherical shell 1405 miles in thickness, the matter of the inward globe being as heavy nearly as melted silver, and the matter of the outward crust being as heavy, at a medium, as Portland stone; then would the weight of such an inward globe, and such an outward shell or crust, be together equal to the present weight of the whole earth. But considering the great compressibility of water, and of the stones and earth met with upon the surface of the globe, it is probable, that in descending to-
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wards its centre, the parts may be so condensed as to make the weight of the earth what it is, without supposing its central parts to be composed of materials different from its superficial parts*.

But to return to our experiment. I need use no arguments to prove that either the sulphur, or the iron, or both, have undergone a great change during their fermentation : we can have no difficulty in thinking that the sulphureous steams, heat, flame, and fire, which attended the mutual action of sulphur and iron upon each other, could not have been produced without the bodies themselves having suffered some change : this change is visible from
inspect-

* See Mr. Michell's very ingenious Essay on Earthquakes.

inspecting the mixture before and after its fermentation; from a greyish colour it will be turned wholly black, or of a deep red; it will be rendered more manifest by tasting it: neither sulphur nor iron have any taste, nor has the mixture of the two any taste before its fermentation; but after that is finished, it has a very saline taste. The nature of the salt contained in it will be examined in the next Essay.

ESSAY

E S S A Y VI.

Of Vitriols, and the reputed Transmutation of Iron into Copper.

THE nature of the residue resulting from the fermentation of iron filings and sulphur, may be easily ascertained. Its taste indicates that it contains some saline substance; in order to see what that substance is, it must be boiled in water; by this means all the salt contained in it, of whatever quality it may be, will be extracted. The water containing the salt in solution being filtrated, evaporated, and

crystallized, according to the usual mode, we shall obtain large saline crystals, of the colour of an emerald, and of the figure of a lozenge. This salt is called *green vitriol*; green from its colour, and vitriol from its resembling *vitrum*, or glass, by its transparency.

This salt certainly did not exist, either in the sulphur, or in the iron, it must therefore arise from their mixture; but from a mere mixture of sulphur and iron, no salt can be extracted, unless the substances of which it consists have been, by some means or other, decomposed. The reader may probably recollect, that sulphur is composed of two things,—of an *acid*, and of *phlogiston*.—Iron also is composed of two things,—of

an *earth*, and of *phlogiston*. During the fermentation of the mass of sulphur and iron, the phlogiston, or inflammable part of them both, is dispersed; and, indeed, in being dispersed, it becomes the cause of the heat, fire, and flame, observable in that mass. The inflammable part, both of the sulphur and of iron, being dispersed, there remains the *acid* of the sulphur, and the *earth* of the iron. The acid of sulphur is a very strong acid, it dissolves many bodies with great facility, and when it is diluted with water, it, in particular, dissolves iron; and, by its union with the earth of iron, it composes the salt in question.

That this is a true explanation of the origin of this salt, will appear evident from the following conside-

ration. If into a quantity of the acid procured from the burning of sulphur, you put a piece of iron, the iron will be wholly dissolved in the acid, as salt is dissolved in water ; and if you saturate the acid with iron, and then evaporate and crystallize the solution, you will obtain a green vitriol, similar, in every respect, to that obtained from the residue of which we are speaking.

The composition of green vitriol has been fully explained, and its decomposition or analysis will still further illustrate its nature, and leave no doubt of the truth of the proposition which asserts, that—*green vitriol* consists of the *acid of sulphur* united to *iron*, or more properly to the *earth of iron*.

If you put 16 ounces of fresh
green

green vitriol into a retort, and distil them till nothing more can be forced into the receiver, by the utmost violence of a long continued fire, you will find in the receiver about 11 ounces of an acid liquor, smelling, in all the trials that I have ever made, very strongly of sulphur; and in the retort you will find about 5 ounces of an earth, of a deep red or purplish colour. The acid liquor, by combining it again with iron, may be made into vitriol; and the earth, by being properly melted in conjunction with any matter which will restore to it its inflammable principle, may be made into iron. The proportionable quantities of acid and earth procurable from green vitriol by distillation, are purposely expressed in terms rather indefinite, because

that proportion is somewhat variable in different vitriols.

The earth remaining from the distillation of vitriol is called *Colcothar*. I would not have troubled the reader with so barbarous a name, but for an observation relative to its use, which may be worth mentioning.

Colcothar is sold for ten pence a pound in *Paris*; it is used for giving the last polish to plate-glass, at the great manufactory in the street *St. Antoine*. The largest plate of glass which had ever been polished in that manufactory, they informed me ten or twelve years ago, was ten feet in length, and six in breadth. The glass is brought from *Picardy*; it is there melted in large crucibles, and spread, whilst liquid,

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upon

upon a table covered with a sheet of copper; much after the same manner in which plumbers cast a sheet of lead. The plate of glass, when first cast, is an inch in thickness; its asperities are ground away with a coarse kind of grit-stone, with sand, and emery, of different degrees of fineness, and it is at last polished by colcothar.

I do not know whether the use of colcothar is adopted in our English plate-glass manufactory near *Prescot* in *Lancashire*, having not been fortunate enough to obtain permission to see it. But, both to the proprietors of that manufactory, and to the patentees for polishing marble at *Asbford* in *Derbyshire*, I take the liberty to suggest, that colcothar, which is very cheap, might perhaps render

the use of *putty*, or calcined tin, less necessary.—Would it not be possible to apply the same kind of machines by which marble is polished to the polishing of plate-glass? — But to return from this digression.

The acid separated from vitriol, by distillation, is called the *vitriolic acid*. From what has been said, relative to the formation of vitriol, it manifestly appears to be the same with that which enters into the composition of sulphur; and indeed the main part of what is sold as vitriolic acid, is now obtained by collecting the vapour of burning sulphur, and not, as it used formerly to be, from the distillation of vitriol.

It must not be imagined, that the acid liquor procured from the distillation of the 16 ounces of vitriol, consists

consists intirely of the vitriolic acid; it consists of that acid diluted with a large portion of pure water. If care had been taken to separate the different products as they arose, during the distillation, we might have procured, by a very gentle fire, six or seven ounces of water wholly insipid: this is the water of crystallization before spoken of*; it is called the *phlegm of vitriol*. After the separation of this water, by a stronger degree of heat we should have obtained an ounce or two of water slightly impregnated with an acid: this is called, *spirit of vitriol*. Lastly, with a very violent fire we should have gotten a very ponderous and strong acid, having an unctuous appearance, and from that appear-

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* P. 125.

ance generally, but improperly, called, *oil of vitriol*. This oil of vitriol is not always fluid; sometimes, when it is exceedingly strong, it has been observed to become solid: in that state it is denominated, *glacial*, or *icy oil of vitriol*.

It was shewn in the last Essay, that natural combinations of iron and sulphur were subject to the same spontaneous changes observable in the artificial mixtures of these substances; and hence we may clearly apprehend the manner in which what are called *native vitriols* are formed in mines and other subterraneous cavities. The pyrites existing in these places being naturally decomposed by the sulphur's parting with its phlogiston, the water which is always dripping in mines, dissolves
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the vitriol generated in the decomposed pyrites; and being afterwards evaporated, either by the heat, or the current of air subsisting in the mine, the vitriol is found in its crystalline form, either projecting like icicles from the top and sides of the mine, or lying in cavities at its bottom. The crystals of *native vitriol* are more or less regular, according to the circumstances attending the evaporation of the water, and they are of different colours according to the quality of the pyrites; for together with the sulphur and iron, the chief constituent parts of the pyrites, there is sometimes combined copper, and other metallic matters, which being dissolved by the acid of the sulphur at the same time that the iron is dissolved, a mixed vitriol is produced,

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the colour of which is sometimes whitish, more generally it consists of different shades of green and blue.

Native vitriol is often met with in our coal mines. From an old *Cannel-coal* pit near *Wigan* in Lancashire, I procured a considerable quantity of it very well crystallized; and Dr. Rutty has observed, that the vitriolic water at *Haigh* in Lancashire is the strongest in Britain, yielding 1920 grains of vitriol from a gallon of water*.

When I was at *Whitehaven*, some years ago, I was informed by the very intelligent superintendent of the coal works in that place, that the bottom
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* *Philos. Trans.* 1756. p. 650. See also, for an Examination of this *Haigh* water, which springs from a stratum of the cannel-coal, Leigh's *Tentamen Philo. de Fonte Med. in Agro Lancas.* C. I.

of a pump of cast iron, which had stood a long time in a well of *vitriolic water*, was so much softened, that, after removing a thin coat of rust, he was able to cut it with a knife, as easily as he could cut black lead; it had preserved its grain, and was not in any wise altered, except in being softened.

At that time, I attributed this softening of the iron to the action of the *vitriolic water*, and thought it a very singular phenomenon: in this, however, I was mistaken; sea water has the same effect. Some iron cannon, which had lain in the sea upwards of sixty years, were weighed up, and the iron was found to be as soft as tin; though in 24 hours, by being exposed to the air, it recovered
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its original hardness*. This softening of iron is not an effect peculiar to the action of either vitriolic or sea water : I have somewhere read of an experiment of softening iron by smearing its surface with the acid of vitriol ; and I have heard of a gentleman, who having frequently stirred saline draughts with his pen-knife, found its temperature much softened thereby. *Diodorus Siculus* mentions a custom of the *Celtiberians*, by which they made their arms of incomparable hardness ; they buried plates of iron under the earth, till the weaker part of the iron was consumed by the rust, and they fabricated their arms from the remainder†. The inhabitants

* Hist. de l' Acad. des Scien. a Paris, an. 1756.

† Diod. Sic. L. V. p. 356.

inhabitants of *Japan* are said to make use of the same artifice †.— The time, however, in which the iron is suffered to lie in the ground, must not be too long; for the iron, instead of being softened and meliorated, will in length of time be wholly changed, as is said to have happened to some Spanish cannon made of hammered iron, which had lain many years under the old fort
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† In itinerariis referunt aliqui de Japonensibus quod ferrum suum in contos excusum locis palustribus immergant, et ibi tamdiu relinquant, dum ad multam partem ferrugine sit consumtum; exemptum dein e novo excudant, et iterum in paludi per spatium 8 vel 10 annorum recondant, usque dum iterum in aqua paludinea salsa admodum exesum sit: pars ferri quæ restat speciem chalybis referre perhibetur, exinde dein vomeres fabricant, exque ferro sic rubiginoso instrumenta sua et utensilia conficiunt. Sweden. de Ferro, Vol. I. p. 194.

at *Hull* in *Yorkshire*; the iron being changed into a brittle kind of stone resembling an iron ore, and refusing to obey the action of the magnet*.

Modern chemists apply the name *vitriol*, to every combination of the acid of sulphur with any metallic substance; three, however, of these combinations are more particularly distinguished, being of great use in various manufactures, — *green vitriol* — *blue vitriol* — *white vitriol*. The acid in all these vitriols is the same: the metallic basis of the green vitriol we have already seen is iron, that of the blue vitriol is copper, and that of the white vitriol is zinc. Vitriol is very commonly called by the manufacturers *copperas*: thus we constantly

* Lister's Journey to Paris, p. 84. Ed. 1699.

stantly hear of green, blue, and white copperas. The constituent parts of the different kinds of vitriols were not understood by the ancients so well as they are at present; they seem to have had an idea, that copper was the basis of them all: hence the Greek term for vitriol, *chalcanthos*, the efflorescence of copper; and the Latin one, *cuperosa*, or *cupri rosa*, the flower or efflorescence of copper; from which the French *couperose*, and our *copperas*, are evidently derived.

The vitriols which nature prepares, are never to be met with in commerce; they serve to adorn the cabinets of the curious, but they are neither sufficiently pure for the purposes to which common vitriols are applied, nor are they found in sufficient

cient quantities to answer the demand which is made for them. Green vitriol is made at *Deptford*, and other places, from a species of the pyrites found on *Shepey Isle*, the *Isle of Wight*, and various parts of the *Essex*, *Kentish*, *Sussex*, and *Dorsetshire* coasts. Large quantities of the pyrites are laid in heaps in the open air, on beds properly prepared; in half a year, a year, two years, sooner or later, according to its quality, the pyrites acquires a spontaneous heat; that heat, without being increased to such a degree as to fire the pyrites, insensibly disperses the inflammable principle of the sulphur, one of the constituent parts of the pyrites; the acid of the sulphur being thus disengaged from the inflammable principle, unites itself to the other principal constituent part
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of the pyrites, the iron, and forms green vitriol. The vitriol thus formed is washed from the pyrites' bed by the rain: the rain-water which has dissolved the vitriol of the pyrites, cannot sink into the earth, the bed on which the pyrites is spread being formed of clay; and being made, moreover, in a sloping position, the dissolved vitriol runs into receptacles properly placed to receive it, and being boiled with old iron till it is of a proper consistency, it is run off into coolers, and left to crystallize. Vitriol may be made without the use of old iron, but the liquor which drains from the pyrites being often not saturated with iron, the iron is added to saturate the acid, and at the same time to purify it from any particles of

VOL. I. P copper

copper it may chance to contain; by this means a pure iron vitriol is obtained, which is known in commerce under the name of English vitriol. The quantity of old iron, in some works, amounts to two hundred weight in making a ton of vitriol.

Much after the same manner, vitriol is made from the pyrites found amongst coal; there are manufacturies of it near *Wigan*, at *Whitehaven*, at *Newcastle upon Tyne*, and in several other parts of the kingdom. But all the vitriol works have sunk in value of late years; the home consumption of vitriol being much diminished since the acid, which used to be procured from the distillation of vitriol, has been obtained from the burning of sulphur.

It is not easy to determine when this method of making vitriol was introduced into England. In the very beginning of Queen Elizabeth's reign, a patent was granted to Cornelius Devoz, for making alum and copperas*; but it was not till towards the end of the last century, that this art of making vitriol was brought to so great perfection as to enable us to export any of it †; and, indeed ‡, a very deep and judicious inquirer into things of this kind assures us, that “at the latter end of the last century, we imported annually about 500 tons of vitriol, and that we now export upwards of 2000 tons.” It appears, that there was exported, from the

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port

* Oper. Min. explicat. p. 26.

† Boyle's Works.

‡ Campb. Survey of Brit. Vol. II. p. 21,

port of London alone, near 400 tons of copperas in three months, January, February, and March, 1776*. A small quantity of vitriol, perhaps to the annual amount of 50 or 60 tons, is still imported into England; some particular dyers and other artists being of opinion, that the foreign vitriol, as containing a little copper, is more useful to them than the English vitriol.

It may easily be known whether green vitriol contains any copper; we need only rub the vitriol to be examined upon a moistened piece of polished iron, for if there is any copper in its composition, the iron will be changed into a copper colour. This experiment renders it necessary
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* See Sir Charles Whitworth's Reg. of Trade, No. I.

to explain to the reader two terms frequently met with in chemical books—*affinity* and *precipitation*.

When two heterogeneous bodies, as an acid and iron, coalesce together, and constitute by their union a third body different from either of them, their union is said to proceed from their mutual *attraction*, or, in the language of German philosophy, from their mutual *affinity*. It may reasonably be conjectured, that the affinity of the same body, of the same acid for instance, may be different with different bodies; its action upon iron may be different from its action upon copper; and its action upon any metallic substance may be different from its action upon any alkaline or earthy substance; because, from whatever at-

tractive powers we suppose its action upon any body to proceed, it seems probable enough, that their effects will be modified, according to the nature of the subject upon which they are exerted. A few instances will make this matter clear.

Spirits of wine very readily dissolve a portion of camphor; that is, the particles of the spirits of wine so powerfully *attract* the particles of camphor, that they unite themselves with the camphor in such a way, as to compose with it a pellucid fluid. Spirits of wine, however, more powerfully attract water than they attract camphor; for if you mix water with camphorated spirits of wine, you will see that the spirits quitting their connexion with the camphor, will unite themselves with
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the water, and the camphor being lighter than water, will rise up to the surface. Lavender water consists of the oil of lavender dissolved in spirits of wine. Into a glass of water, drop a few drops of lavender water; the spirits of wine will quit the oil, in order to unite themselves with the water, and the oil being lighter than water will float upon its surface. In both these cases, the spirits of wine are said to have a greater affinity with water, than with camphor or oil of lavender.

Into a solution of green vitriol, drop a solution of pot-ash, salt of tartar, or any alkaline salt; the vitriolic solution will let fall a sediment: continue to mix the alkali with the solution of vitriol, till no more matter falls to the bottom; the

matter which falls to the bottom, is
 said to be *precipitated*, and it is often
 called a *precipitate*. This effect may
 be thus explained:—green vitriol
 consists of two things,—of an acid;
 and of an iron earth; but the acid
 has a greater disposition to unite it-
 self with any alkali, than it has to
 continue united with the earth of
 iron; when therefore an alkali is
 presented to it, it quits the iron
 earth, which, thus wanting its sup-
 port, falls to the bottom, and unites
 itself with the alkali. The acid of
 vitriol is therefore, on this account,
 said to have a greater affinity with any
 alkaline salt, than with iron, because
 any alkaline salt will separate the
 iron from the acid. What is precipi-
 tated may be made into iron; and if
 the liquid which floats upon the pre-
 cipitated

precipitated earth, be evaporated and crystallized, it will give the very kind of salt which would arise from a direct combination of the acid of vitriol with the alkali which occasioned the precipitation. I will mention one other instance.

Blue vitriol consists of copper united with the acid of vitriol: if to a solution of blue vitriol you add a piece of bright iron, it will presently become covered with a coppery coat, the copper will all be *precipitated*, and the iron will be *dissolved* in its stead. The proof of this reasoning is easy: the matter which is precipitated may be melted into copper, and the liquid part may, by evaporation and crystallization, be made, not into *blue*, but into *green vitriol*; that is, into a combination of
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the vitriolic acid and iron. Hence it is said, that the acid of vitriol has a greater affinity with iron, than it has with copper, because it quits copper to unite itself with iron. In order to be convinced of the truth of what is advanced, we need only dip a bright key into a solution of blue vitriol, and we shall see the key presently becoming covered with a copper-coloured pellicle.

This experiment explains to us, in a very satisfactory manner, the nature of that *transmutation of iron into copper*, which travellers have been so much surpris'd at. Agricola speaks of waters in the neighbourhood of *Newsol* in *Hungary* which had the property of transmuting the iron which was put into them into copper *. In the year 1673, our

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* Agric. Fos. L. IX. p. 347.

countryman Dr. Brown visited a famous copper mine at *Herrn-Grundt*, about seven English miles from *Newsol*; he informs us that he there saw two springs, called the old and new *ziment*, which turned iron into copper. The workmen shewed him a curious cup made of this transmuted iron; it was gilt with gold, had a rich piece of silver ore fastened in the middle, and the following inscription engraved on the out-side:

*Eisen ware ich, kupfer bin ich,
Silver trag ich, gold bedeckt mich.*

Copper I am, but *iron* was of old,
Silver I carry, covered am with gold*.

It was even at that time, he says, contended by some, that there was no real transmutation of iron into
copper,

* Brown's Travels, Ed. 1687. p. 69.

copper, but that the ziment water, containing vitriol of copper, and meeting with the iron, deposited its copper; and it seems as if he would have acceded to this opinion, could he have told what became of the iron. It is now very well understood what becomes of the iron; it is taken up by the water, and remains suspended in it, in the place of the copper; so that this transmutation is nothing but a change of place; and as the copper is precipitated by the iron, so the iron might be precipitated by pot-ash, or any other substance which has a greater affinity with the acid of vitriol than iron has.

The cause of the impregnation of these copper waters in Germany is not difficult to be explained. Most copper ores contain sulphur, and
when

when the sulphur is in any degree decomposed, its acid unites itself to the copper, and forms blue vitriol, which is the substance with which the waters issuing from the copper-mines are impregnated. It has been the custom in Germany, for some centuries, to collect the copper contained in these waters; the method is simple: into pits filled with the coppery water they put old iron; the iron is dissolved, and the copper is precipitated, and being raked out in the form of mud, it is afterwards melted into very fine copper. The quantity of copper procured by an hundred tons of iron, is not always the same; it sometimes amounts to 90 tons, and seldom to less than 84*.

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* Miscel. Curi. Germ. Ann. 6 & 7, p. 158, where

The progress of arts is in many instances wonderfully slow. Though this method of obtaining copper has been long practised in Germany, yet it is but of late years that any successful attempts of this kind have been made in either England † or Ireland; and that they have been made at all has, in Ireland at least, been owing not to the example which had been set in Germany, but to an accident.

There are very celebrated copper-mines at *Arklow* in the county of *Wicklow* in Ireland; and from these
mines

where there is mention made of an oak leaf being changed into copper—the iron contained in the leaf, probably precipitating the copper.

† An attempt was made in 1571, to transmute iron into copper, near Pool in Dorsetshire. Hutch. Hist. of Dorset, Vol. II. p. 110,

mines there issues a great quantity of water, strongly impregnated with the vitriol of copper. One of the workmen having accidentally left an iron shovel in this water, he found it, some weeks after, so incrufted with a coat of copper, that it was thought to be changed into copper. The proprietors of the mines, in purfuanee of this hint, made proper pits and receptacles for the water, and have obtained, by means of soft iron bars put into the coppery water, fuch quantities of copper, as render the freams of as much confequence as the mines. One ton of iron produces near two tons of copper mud; and each ton of mud produces, when melted, 16 hundred weight of copper, which fells for 10 pounds a ton,

more

more than the copper which is fluxed from the ore *.

There is a mountain in the isle of *Anglesey*, called *Paris* mountain, which abounds in copper ore; the bed of ore being above forty feet in thickness. The lessees of this mine annually raise between six and seven thousand tons of merchantable ore, and daily employ above forty furnaces in smelting it. The ore is not rich in copper, but it contains a great quantity of sulphur, which must be separated from it, before it can be fluxed into

* *Philos. Transf.* for 1751 and 1752, p. 502, and for 1756. — Iron often contains gold; the vitriolic acid has no action upon gold; is not the gold contained in the iron mixed with the precipitated copper, and may it not be worth while on this account to assay this copper?

into copper. The ore is accordingly roasted; the phlogiston, together with part of the acid of the sulphur, is, by the violence of the fire to which it is exposed in roasting, dispersed into the air: another part of the acid attacks and dissolves the copper. The water in which the roasted ore is washed is so strongly impregnated with copper, that they have found it useful to adopt the German method of precipitating it by means of old iron, and they have obtained in one year near one hundred tons of copper precipitated from this water.

The water, after the copper has been precipitated by means of iron, is at present thrown away; it would, by evaporation, yield *green vitriol*; and as above one hundred tons of

iron must be employed in obtaining the forementioned quantity of copper, it may deserve to be considered, whether a *manufactory of green vitriol* might not be established at this and at all other places where *copper* is obtained by *precipitation*. One hundred tons of iron would yield, at the least, two hundred tons of vitriol; which, at the low price of three pounds per ton, would be more than sufficient, I suppose, to pay the expence of extracting it; especially, as means might be contrived of evaporating the watery solution, by a proper application of part of that heat, which is at present lost in all the great smelting-houses. There are other purposes to which this water might be usefully applied, which I cannot insist upon in this place. The

The principal use of green vitriol is, in dying, and in making of ink. When the vitriol is dissolved in water, the iron contained in it becomes black by the addition of an infusion of gall-nuts. Galls are excrescences from the oak; they are formed from the exudation of the juices of the oak: this exudation is not spontaneous; it proceeds from the puncture made in the bark by an insect: in the hole which it has made, it deposits its egg, and the exuding juice hardening, forms a proper *nidus* for it. Most of the galls have holes in them, the young insect having eaten its way through the substance in which it was hatched: in many of those which have no holes, the insect may be discovered in the inside, by breaking the gall. The property

which an infusion of galls has, of tinging a solution of vitriol black or purplish, renders it serviceable in discovering the minuteſt portion of iron in chalybeate waters. I took one grain of vitriol (a grain of vitriol does not contain quite half a grain of iron) and diſſolved it in 15 gallons of water; the water, upon the addition of an infusion of galls, became ſenſibly purple. Other *aſtrin-gent* vegetables have a ſimilar effect on vitriol, but not in the ſame degree.

I will conclude this ſubject with mentioning an experiment, which, when proſecuted by a ſkilful manufacturer, may, I ſhould hope, ſome time or other, become of general ſervice.

I took a piece of dry oak, which had been felled about a year; I

rasped off from the bark, from the sap, and from the heart of the wood, equal weights, and put them into equal portions of hot water. After they had stood some time, it was apparent, that the bark had given an higher colour to the water than the heart had done; and that the water in which the sap was put, had extracted the least colour. Into equal portions of a solution of green vitriol, I put equal parts of these several infusions, expecting to have seen the vitriol turned black by them all; but the event was, that the *sap* infusion produced very little change of colour; the *bark* infusion gave a dark brown; and the *heart* infusion instantly gave one of the most *vivid blues* I ever saw. If the raspings of heart of oak be boiled

for an hour in water, they lose this property of forming blue with vitriol; but the cold infusion forms a fine blue; and if a solution of vitriol be poured upon the raspings, the whole is changed into a blue mass.

ESSAY

E S S A Y VII.

Of Nitre or Saltpetre, and the application of its Acid to the inflammation of Oils, and the congelation of Quicksilver.

SOME of the more ancient chemical writers were accustomed to make a distinction between *nitre* and *saltpetre*; they are now used as synonymous terms. The constituent parts of nitre are two; — an *acid*, and the *vegetable fixed alkali*. This proposition may be proved both by the *decomposition* and the *composition* of nitre.

Nitre may be *decomposed* in the following manner. — Upon two parts of nitre by weight, pour one part by weight of strong acid of vitriol, and distil the mixture. You will obtain thereby, a very strong *acid*, of a yellowish colour, and a most suffocating smell, and which has the singular property of emitting *red fumes*; by the addition of water the colour may be rendered *blue* or *green*, but the fumes will still be red. This is the *acid* or *spirit of nitre* *; and it is sometimes called *Glauber's fuming spirit of nitre*, because Glauber is generally

* The word *spirit* is used by chemical writers with great latitude; it is applied to *acids*, as the spirit of vitriol, of nitre, of sea salt, &c. and to *volatile alkalies*, as the spirit of sal ammoniac, of hartshorn, &c. and the inflammable fluid obtained by distillation from wine, &c. is eminently entitled to the name of spirits.

generally supposed to have been the first inventor of this manner of extracting it.—Two things were distilled together, the acid of vitriol and nitre. Nitre itself, we say, consists of two things; of a peculiar kind of acid, and of the vegetable fixed alkali: the acid, we have seen, may be extracted by distillation; there ought, therefore, to remain, in the vessel used for the distillation, the *acid of vitriol* and the *alkali* of the *nitre*: and there really does remain nothing else; for the residue, when dissolved and crystallized, is found to be the very same kind of salt, in all its properties, as would arise from the direct combination of the acid of vitriol with the vegetable fixed alkali. We need not wonder, that we do not find the alkali of
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the nitre and the acid of vitriol in their separate forms, but united together into a particular kind of salt; for the acid of vitriol has a strong disposition to dissolve all kinds of alkalies; it attracts them with more force than they are attracted by any other acid; and it was in consequence of this superior attraction of the acid of vitriol, that the acid of nitre was disengaged from its other component part: the acid of vitriol expelled, as it were, the acid of nitre from the fixed alkali, and substituted itself in its place.

There are various other methods of decomposing nitre besides that which has been mentioned; those who prepare *aqua fortis*, usually distil the nitre in conjunction either with clay or with green vitriol, calcined

to a certain degree. The acid of vitriol is contained in many kinds of clay, as well as in green vitriol; but it leaves both the clay, and the iron of the green vitriol to unite itself with the alkali of the nitre; and the acid of nitre being thus set at liberty by the intervention of the acid of vitriol, and being also of a volatile nature, it is easily made to ascend in vapour, which, being collected in proper vessels, becomes the *aqua fortis* of the shops.

It may appear from what has been said, that the *acid of nitre* and *aqua fortis* are but different names for the same thing: the matter is not quite so, unless the reader will understand by *aqua fortis*, *pure aqua fortis*; for whenever the acid of vitriol, or any substance containing it, is used in
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the process for decomposing nitre by distillation, a portion of the acid of vitriol is distilled in conjunction with the acid of nitre: hence the common aqua fortis may be considered as a pure acid of nitre, mixed with a portion of the acid of vitriol. This portion of the acid of vitriol is thought to render the aqua fortis fitter for the purposes of some particular artists: thus *engravers* and *etchers* use an aqua fortis which contains about one tenth of its weight of the acid of vitriol; and the proportion of acid of vitriol, which enters into the aqua fortis used by *dyers*, is still much greater. It is necessary for *refining silver*, and for many other purposes, to have the acid of nitre quite pure. This may be effected, either by purifying the common
aqua

aqua fortis by various means well known to chemists, or by distilling nitre with some substance which contains no acid of vitriol; for though it be certain, that the acid of vitriol is very serviceable in disengaging the nitrous acid from its basis, yet it is also certain, that the nitrous acid may be disengaged, without the assistance of the vitriolic acid: thus I remember having many years ago obtained a very strong *fuming* acid of nitre, by distilling *nitre* with *white sand*, which contains no acid of vitriol.

The artificial *composition* of nitre is easily effected. Take a portion of the nitrous acid, and pour it into a solution of pot-ash, of salt of tartar, or of any other vegetable fixed alkali, till no more effervescence is observed :

served: evaporate and crystallize the compound, and you will obtain a perfect nitre. This is usually called a *regenerated nitre*; and we may often see crystals of nitre almost instantaneously produced, by mixing a solution of pot-ash with a nitrous acid of a due degree of strength.

In time of war with an enemy who has plenty of pot-ash but no saltpetre, the supplying him with *aqua fortis* ought to be prohibited under as severe penalties as the supplying him with saltpetre itself; because, if he can procure the *aqua fortis*, it will be an easy matter for him, by mixing it with his pot-ash, to make regenerated nitre. The nitre may come a little dearer to him than common nitre would do; but it is at the same

same time purer, and fitter for the preparation of gunpowder.

Though chemistry exhibits to us a great variety of striking phenomena, yet there is none more surprising than that which attends the mixing of the *fuming acid of nitre* with *oil of turpentine*. If you mix these two fluids together in the severest weather, and when they are severally colder than ice, you will see them instantaneously catching fire, and bursting forth into a dreadful flame. This experiment does not always succeed with the acid of nitre which may ordinarily be procured from the shops, because it is seldom sufficiently strong; but when it does succeed, there is great danger in making it, especially if the quantities which are mixed together

amount

amount even to a few ounces. I have several times seen a thick column of flame and smoke, above twenty feet in height, instantaneously produced, by pouring, at once, a pint of the fuming acid of nitre on a pint of oil of turpentine. Whoever undertakes to make a similar inflammation, would do well to use the precaution of fastening the vessel containing the acid to the end of a long pole, to prevent his being burned by the drops of inflamed oil, which are dispersed, laterally, by the explosion to a great distance.

Borrichius, in the year 1671, is thought to have been the first person who noticed the phenomenon here spoken of: since that time the chemists of all countries have employed
much

much attention in repeating and diversifying this celebrated experiment. In the Philosophical Transactions for 1699, we have a table expressing, at one view, the effect which the acid of nitre has upon a variety of other oils, as well as upon the oil of turpentine: we there find enumerated 12 sorts of oils, which, when mixed with acid of nitre, effervesced, and exploded with a flame; 18 sorts which effervesced, but did not take fire; and 9 sorts which neither effervesced nor took fire. In addition to the information contained in this table, we are indebted to the French chemists, for a variety of interesting memoirs on the inflammation of oils; both by the simple nitrous acid, and by that acid when mixed with the

acid of vitriol. The reader will, perhaps, be satisfied with a general reference to the most approved authors * on the subject; especially as there is not any very satisfactory solution given of the phenomenon.

We know that a piece of iron may be hammered till it glows with heat; that the axle-tree of a carriage may be so heated, by the rapidity of the motion, or the violence of the friction, as to inflame the wood contiguous to it; that two pieces of wood

may

* See Mem. del l' Acad. de Par. Ann. 1701. 1726. 1747. and Macquer's Elem. of Chem. Vol. II. p. 149. Eng. Transf. and especially Musschenbroek's Additions to the experiments of the Florentine Academy. This industrious philosopher has there given us above 200 different experiments, illustrating the change of temperature arising from the mixture of water; of spirits of wine; of vinegar; of the mineral acids; with a great variety of other bodies.

may by friction be made to take fire; and we infer from these, and other appearances of the same kind, that the motion excited by the action of particular acids upon particular oils, is sufficient to produce that degree of heat which is requisite to inflame the oils.

It does not seem to be a simple mixture of two ingredients which produces heat; they must act upon each other in a manner different from what accompanies a simple mixture, and this action does not always take place immediately. Thus, if we mix 2 parts of spirit of wine with 1 part of fresh fuming acid of nitre, the mixture will often remain cold for near ten minutes, but it will at last begin to acquire a great degree of heat, and it will boil with great

R 2 violence

violence for a considerable length of time. In like manner, by mixing together equal bulks of strong acid of vitriol and water, we may excite a degree of heat greater than that in which water boils : but it is not a simple mixture which takes place on this occasion, the very texture of the bodies seems to be broken ; for the compound occupies less space than what the two ingredients would have occupied, had there only been a simple mixture. A pint of water mixed with a pint of oil of vitriol will not make a quart, as it would do, if mixed with a pint of milk ; but then no heat would attend its mixture with milk, and a very great degree of heat attends its mixture with the acid of vitriol. It cannot be said, that the acid of vitriol is re-
ceived

ceived into the pores of the water ; for then a small portion of acid might be dissolved in a large portion of water, without augmenting its bulk * ; but the very form of the bodies is changed ; there is, in the words of Dr. Hooke, (who first observed that acid of vitriol and water when mixed together possessed less space than when separate) a *penetration of dimensions* †.—Is heat ever excited by the mixture of two fluids, when the bulk of the compound is equal to the sum of the bulks of the two ingredients ?

Strong acid of nitre, when mixed with common water, or with snow water, produces a great degree of heat ; when mixed with water con-
gealed

* Philos. Transf. 1770. p. 353,

† Hauksbee's Exp. Ed. 1719. p. 294.

gealed into ice, or snow, it produces the greatest degree of cold which has ever been observed on the surface of the earth ; and this property of the acid of nitre has given occasion to one of the finest discoveries of the present century,—the conversion of quicksilver into a malleable metal.

In the year 1759, upon the 14th day of December old stile, there was observed a greater degree of *natural cold* at *Petersburgh*, than had ever before been noticed, since the time that the Academy had kept Meteorological registers ; Fahrenheit's thermometer standing at 66 degrees below the freezing point. In a few days the cold grew more intense, so as to make the thermometer, on the 26th of the same month, sink to $74\frac{2}{3}$ degrees below freezing. This is

esteemed the greatest degree of natural cold which has hitherto been observed at Petersburg. This cold, though very great when compared with what we experience in England in the severest seasons, is far less than what is ordinarily felt in *Siberia*; 120 degrees below the freezing point, having been often observed; and on the 5th of January 1735, the thermometer fell to 157 degrees below freezing*. When this degree of cold was first published to the world by Gmelinus, who made the observation at *Jeneseisk*, many
 suf-

* In the treatise (Novi Commen. Petrop. Tom. XI.) from which this account is principally extracted, the degrees of heat and cold are estimated upon the scale of De Lisle's thermometer; but Fahrenheit's being more known in England, I have every where substituted the corresponding degrees of Fahrenheit's scale in the place of the other.

suspected the truth of the account, or questioned the accuracy of the observation; but their suspicions were ill founded, for an equal, if not a greater degree of cold was observed in *Sweden* in 1760 †; and we shall see presently that a cold even greater than what is here mentioned, has been experienced in other places of *Siberia*, as well as at *Jeneseisk*.

Fahrenheit in 1729 had tried what degree of artificial cold he could produce, by dissolving pounded *ice* in strong *acid of nitre*; and he was very much surpris'd at the event of his experiments, for the quicksilver sunk to 72 degrees below the freezing point. Boerhaave calls this discovery a thing incredible before, and asks

† *Novi Comm. Petrop.* Tom. VI. p. 39.
Sum. Dis.

asks with astonishment, what mortal could ever have thought of it? Nature, says he, had never produced a degree of cold greater than 32 degrees below freezing; and all animals and vegetables exposed to such a severity of cold instantly perished*. In this observation Boerhaave was certainly mistaken; for both animals and vegetables can exist in degrees of cold which are far superior even to the utmost artificial cold which Fahrenheit produced. Several philosophers have, at different times, repeated Fahrenheit's experiment, but without being able to produce a greater degree of cold than he had done.

Professor Braun, at last, on the 14th of December, in the year before

* Boerh. Chem. Vol. I. p. 162.

fore mentioned, began his experiments, with no other view than that of producing a greater degree of cold than any person had done before him; for he rightly conjectured, that the greater the degree of *natural* cold prevailing in the air, the greater would be that of the *artificial* cold. With this design he followed, in his first attempts, the process of Fahrenheit, pouring the acid of nitre on powdered ice; and he succeeded to his wishes, having made the mercury sink to 100 degrees below the freezing point. With hopes of producing a still more remarkable cold, he continued his experiments; in the course of which, having used all his powdered ice, he substituted snow in its stead, and to his infinite surprize and satisfaction, he found the

the mercury had descended to 384 degrees below freezing. Suspecting that his thermometer was broken, he took it out of the mixture, and found it uninjured ; but he was beyond measure astonished at seeing the quicksilver remain for some time immoveable in the tube : it did not begin to ascend till it had stood above 12 minutes in a warm room. He communicated this discovery to the Academy at Petersburg, on the 17th of the same month, and stated the congelation of quicksilver as a probable truth ; for he had concluded it to be frozen, from its remaining for so long a time immoveable in a warm air. In a few days he repeated his experiments, and purposely breaking the bulbs of several thermometers, he observed the
mercury

mercury to be congealed in them all. This *congealed mercury* resembled the most polished silver in lustre; was in sound and consistency like lead; for he hammered it, and cut it with a knife, before the heat of the atmosphere reduced it to its former fluid state. This wonderful discovery excited the attention of his colleagues in the Academy; his experiments were successfully repeated by several of them; and it was further observed, that solid mercury sunk in fluid mercury, after the manner of metallic substances in general.

The congelation of quicksilver, notwithstanding the accurate account given of it by Braun, and the many eye-witnesses of the fact, has been questioned by counsellor Lehman of Petersburg. According to
his

his observation, “ the mercury employed by professor Braun in his experiments, was distilled in the common way, through water, and the water only was frozen, and not the mercury itself; but having employed mercury distilled without water, and carefully purified from all watery particles, the mercury would not congeal, although common mercury did freeze when set in snow mixed with spirit of nitre, or spirit of sal ammoniac*.” In reliance upon the justness of this observation, it has been affirmed that mercury “ is a semi-metal, which continues fluid in the most intense freezing, either natural or artificial,

or

* Counsellor Lehman's Observations, quoted by Dr. Forster, in his Introduction to Mineralogy, 1768. p. 32.

or when both are combined." I do not think this objection of counsellor Lehman of much weight, when put in competition with the great number of experiments which Braun appears to have made with accuracy, and related with fidelity. He himself hints at this objection, in the supplement which he published to the account of his discovery; but he does not formally refute it, as not thinking it of sufficient consequence *. The vapour of distilled mercury is indeed generally condensed in water; but the mercury is afterwards strained through leather, and otherwise cleansed;

* Cogitarunt quidam mercurium forsitan vel ob impuritatem, vel ob admixtam mercurio aquam congelari, sed hæc hypothesis quam quidam sumserant, est falsissima, omnem in corporibus fieri congelationem ob aquam contentam. Novi Com. Petro, Tom. XI. p. 307.

cleanfed ; fo that I do not apprehend that it contains any water, efpecially that which is ufed in thermometers ; for in making of thermometers, the mercury is expofed to a great heat, which would effectually diffipate any particles of water, if any were left adhering to it.

The author of this fine difcovery has made many experiments, in order to determine what is the fmalleft degree of natural cold which is requifite to make the congelation of quickfilver by an artificial cold, arifing from the mixture of acid of nitre and fnow, fucceed ; and he is of opinion, that the degree of natural cold ought not to be lefs than 30 degrees below the freezing point, to make the congelation begin ; and that it ought to be 42 degrees

degrees below freezing, to make the congelation complete. It seems, if we may rely upon these experiments, that we can have very few opportunities of attempting on rational grounds to freeze quicksilver, by means of snow and acid of nitre; for it very rarely happens that the natural cold in England is 30 degrees below the freezing point, at least near the surface of the earth. This restriction is added on account of some observations which are said to have been made at *Glasgow*, in January 1780. On the 14th of that month, at six o'clock in the morning, a thermometer placed upon the snow in the observatory park, stood at 55 degrees below freezing, whilst one laid upon the snow near the surface of the earth, was only

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18 degrees below freezing. This difference probably proceeds from hence, that the body of the earth warms the air which is contiguous to it, and thus counteracts the cold, which may be accidentally generated in the atmosphere, more powerfully near its surface, than at any great height above it. It would be worth while to observe the temperature of the air, at the bottom and at the top of the Monument, or any other high building in the form of an obelisk, at all seasons of the year, especially in winter time, as greater degrees of cold may probably prevail, from the fall of snow and other causes in the air, at the top of an high building than at the bottom, especially if the building tapers up into a point, so as not to

afford a great mass of matter to heat the ambient air.

The precise degree of cold requisite to freeze mercury, cannot be ascertained on account of the sudden and irregular contractions which it is observed to suffer, just before it begins to be solid; it continues to descend, after the part contiguous to the bulb of the thermometer begins to freeze; but probably, not less than 600 degrees below freezing, are requisite to congeal it wholly. It is remarkable, that oil of sassafras wood, of chamomile flowers, the liquor which remains from the boiling of sea salt, and several other fluids continued uncongealed, in the same degree of cold in which mercury was frozen.

Since

Since the discovery of the congelation of quicksilver made by professor Braun, philosophers have been very attentive, in many places, to effect the same thing by the same artificial means ; and they have succeeded in some places, particularly at Albany fort in Hudson's Bay, where quicksilver was frozen by Mr. Hutchins on the 19th of January, 1775, the cold of the air then being 60 degrees below the freezing point. In this account it is observed, that the standard thermometer, when taken out of the mixture of acid of nitre and snow, fell 10 degrees lower than when the bulb was immersed in the mixture. A similar phenomenon had been observed by professor Braun more than once ; and he accounts for it from the acids continuing to dissolve the

snow adhering to the thermometer.
 —May it not proceed from the quickness with which the moisture adhering to the bulb of the thermometer is evaporated, in consequence of the great warmth of the air when compared with the coldness of the moisture*? The Russians being more favourably situated than most other philosophers for making experiments on the effects of cold, it is from them that we must expect the further prosecution of this subject; I will therefore lay before the reader, an account of the congelation of quicksilver, by the *natural* coldness of the atmosphere, which prevailed at *Krasnoyarsk*, in the southern part of the province of *Tobolsk*: the account is

* Philo. Tran. 1776. p. 174 & 590.

is translated from M. *Pallas*' tour through Siberia, Vol. IV. Part iii. 1763.

“ The winter begun this year very early, and was felt with uncommon severity in the month of December. On the 6th and 7th of that month, there was the hardest frost that I have ever observed in Siberia; the air was calm, and as it were thickened; so that in a quite clear sky, the sun was seen as through a fog. On the sixth in the morning, I observed my thermometer, which had been carefully made, but was not graduated above 102 degrees below freezing; the quicksilver was sunk into the bulb, except some small pieces which were *clodded* together, and stuck in the stem: this was an accident which I had never

experienced with the same thermometer, though I had used it eight years. Upon carrying the thermometer into a warm room, the clodded pieces fell immediately into the bulb, but the quicksilver did not begin to ascend till near a minute after. I repeated this experiment several times with the same success, there remaining in the tube sometimes only one, sometimes several little pieces of *frozen quicksilver*. When the quicksilver in the bulb was warmed by the application of a finger, it presently rose; and it was plainly seen, that the part which was frozen in the stem resisted the rise of the quicksilver a considerable time, and was at last thrust upwards, ascending with a sort of violence. I exposed to the cold about a quarter
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of a pound of quicksilver in an open vessel; the quicksilver had been cleansed as much as possible by vinegar and leather, and it was well dried: in less than an hour its surface was frozen, and in some minutes after it was all condensed by the natural cold into a soft substance like pewter. When the inner part was yet in a fluid state, the surface being broken, was wrinkled in some places, but the greatest part remained pretty even in freezing, as was the case also with a larger quantity of quicksilver, which was frozen upon another occasion. The frozen matter of quicksilver was more flexible than lead, but more brittle than pewter, and when hammered into thin plates, it seemed somewhat granulated; but if the hammer was not

perfectly cooled, then the quicksilver glided from it in drops; the same happened if it was touched by the finger. In a warm room the quicksilver thawed like wax over the fire, and did not melt all at once. If the frozen mass was broken in the cold, the pieces clung together, and stuck to the sides of the vessel wherein they were placed. Though the frost towards the night seemed to abate a little, yet the frozen quicksilver remained unaltered, and the experiment with the thermometer could still be repeated. On the 7th of December I had, during the whole day, occasion to make the same remarks; but some hours after sun-setting, there came on a north-west wind, which raised the thermometer to 78 degrees below freezing, when

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the quicksilver begun to dissolve. Shortly after this, I was favoured with an account from M. Lieutenant General *de Bril*, Governor of *Irkuzk*, that in the same town at 4 o'clock in the morning of the 9th of December, the mercury had been found fast frozen, both in the thermometer and barometer, both of which had been made by professor Laxman when he resided in Siberia. It stood in the barometer 27 inches 7 lines, and the upper five lines were quite broken, but it was liquid again at 11 in the forenoon. The thermometer was clodded at 76 degrees below freezing; and under the 91st degree below freezing there was an empty space of near 11 degrees. Towards 11 o'clock all was gone into the globe, and at one o'clock when
it

it was again come into motion, it shewed 124 degrees below freezing."

From these discoveries of the Russians we are fully authorized in considering quicksilver as a metal, which requires a greater degree of cold to keep it in a solid state than is ordinarily met with upon the surface of the earth : gold, and silver, and iron, if carried nearer to the sun, would be perpetually fluid ; and quicksilver if removed further from it, would be perpetually solid ; nay, it may be fairly doubted, I think, whether there may not be elevated places upon the surface of the earth cold enough to keep quicksilver in a solid state, at least during the greatest severity of winter.

E S S A Y VIII.

*Of the manner of making Saltpetre
in Europe, and of its generation.*

SALTPETRE enters in a large proportion into the composition of gunpowder ; hence, after the discovery of gunpowder, all the states of Europe were eager in their endeavours to amass large quantities of saltpetre, and studiously sought out various methods of preparing it ; for saltpetre is by many looked upon as the production of art rather than of nature.

Gun-

Gunpowder was very probably made in *England* so early as the year 1417. In *Henry V.*'s directions for equipping his fleet with all requisites, under the general name *stuffura*, we find mention made of *Carbonarii*, and of *viginti piparum de pulvere de carbonibus salicis**: these twenty pipes of willow-coal powder, could be for no other purpose, one would think, than for the making of gunpowder, if gunpowder itself did not come under that denomination. Three years before this, a proclamation had been issued, forbidding the exportation of gunpowder ; and, in those early ages of commerce, it may be thought unlikely that gunpowder would be first imported into *England*, and then exported again. Hollingshed in his
Chro-

* Rymer's *Fœder.* Tom. XI. p. 543.

Chronicle, speaks of the capture of two French vessels in 1386, with a great quantity of gunpowder, which, he says, was more worth than all the rest of the cargo ; but had no gunpowder been then made in England, it would have been natural for him to have mentioned that circumstance. This, however, is mere conjecture, and a more diligent search into antiquity may, perhaps, shew it to be ill founded. There is a diversity of testimony on this subject ; one author* asserting, that Queen Elizabeth was the first of our princes who caused gunpowder to be made in England ; another † informing us, that a house near the Tower, in which gunpowder was made, was blown up in the reign of

* Baker's Chron. p. 399. Edit. 1696.

† Hollingshed's Chron. year 1552.

of Edward the Sixth, and fifteen gunpowder-makers slain by the accident. But, whenever gunpowder was first made in England, it is not without reason, that we suppose it to have been made of saltpetre manufactured in England ; since it is not at all likely that any foreign power would permit the exportation of so important, and, at that period, so scarce a commodity.

Before such large quantities of saltpetre were imported from the East-Indies, the manufacturing of it in England was much attended to ; though it appears, from a proclamation of Charles the First, in the year 1627, that the saltpetre-makers were never able to furnish the realm with one-third part of the saltpetre requisite, especially in time of war.

This

This proclamation was issued in 1627, in consequence of a patent granted, in the year 1625, to Sir John Brooke and Thomas Ruffel, for making saltpetre by a new invention *. In this new invention, great use was made of all sorts of urine ; for the proclamation orders all persons to save the urine of their families, and as much as they could of that of their cattle, to be fetched away, by the patentees or their assigns, once in twenty-four hours in the summer, and in forty eight hours in the winter season. This royal proclamation was no small inconvenience to the subject ; but it was not so great a one as that, by which the saltpetre makers were permitted to dig up the floors of all dove-houses, stables, &c. the proprietors

* Rymer's Fœd. Tom. XVIII. p. 813.

prietors being at the same time prohibited from the laying of such floors with any thing but mellow earth: To this grievance all persons had been subjected by a proclamation in 1625, which was revived in its chief extent in 1634, the new invention not having answered the purpose for which the patent had been granted; and it was not till the year 1656, that an act of parliament passed, forbidding the saltpetre makers to dig in houses or lands, without leave of the owners.

As in England the earth impregnated with the dung of pigeons, the urine of cattle, &c. was formerly supposed to belong to the crown; so in France, the rubbish of all old houses, the mellow earth of stables, cellars, &c. does at present belong to the king.

king. In the dominions of the king of Prussia, and in many parts of Germany, the inhabitants are obliged to build mud walls of any fat earth mixed with straw ; and these walls, in a longer or shorter time, according to the quality of the materials of which they are built, and the situation in which they are placed, become impregnated with saltpetre.

There are a great many materials from which saltpetre may be made ; in general, all animal and vegetable substances, when mixed with limestone earths, or marles of different sorts, in such proportion as to excite a putrefaction in the mass, are proper for this end. The parts of animals, without any addition of earth, are said to yield saltpetre by putrefaction ; urine slightly putrified gives

saltpetre in a small quantity ; being fully putrified it yields it more abundantly *. Kunckel took fresh blood, and left it to putrify in a warm place till it was reduced to earth ; he obtained, by this means, above five pounds of saltpetre from one hundred pounds of blood †. If this experiment may be generally relied on, it might, perhaps, be worth while to extract the saltpetre from the earth remaining in the blood and garbage holes of slaughter-houses. The method of extracting saltpetre from the earths in which it is generated, is much the same in all countries. It consists in pouring water upon the earths, to dissolve all the salt, of whatever kind, which is contained in them ; in passing this water through wood

* Junck. Chem. Vol. II. p. 296.

† Id. p. 235.

wood ashes, in order to supply the unformed parts of the saltpetre with a proper alkaline basis; and in evaporating the solution, till it be of a proper strength to shoot into crystals. The saltpetre obtained by this first crystallization, is seldom pure enough for the purposes of making gunpowder, or of medicine*.

I do not know that we have at present any saltpetre works established in England. There have been many projects proposed for making it, both in the last and present century,

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* The reader who wishes to know more of the manner of making saltpetre, may consult a very good paper of Mr. Henshaw's, in Bishop Sprat's History of the Royal Society, p. 260. or Newman's Chemistry, published by Lewis, p. 197. or Glauber's Prosperity of Germany, or Clarke's Nat. Hist. of Saltpetre: the manner of making it in Podolia is described in Philos. Transf. 1763.

tury, but they have all ended more to the disadvantage than the emolument of the undertakers. The Society for the Encouragement of Arts and Manufactures in vain proposed premiums for the making of saltpetre, from the year 1756 to 1764* : these premiums were never claimed, and a saltpetre work which was, about that time, established at the expence of above six thousand pounds, was at last abandoned ; the proprietors having been experimentally convinced, that they could not afford to sell their saltpetre for less than four times the price of that imported from India. The reason of this constant failure in all attempts to make saltpetre with profit in England, may be attributed partly

* Doffie's Memoirs of Agriculture, Vol. I. p. 197.

partly to the nature of the climate, which probably does not generate saltpetre so abundantly as some other climates do ; but principally, it is apprehended, to the dearth of the wood ashes generally used in preparing this substance, and to the high price of the labour which must be employed in collecting and manufacturing the materials.

How far wood ashes are in all cases necessary for the extraction of saltpetre from the earths containing it, may be much questioned from the result of the following experiment.

From an old barn, belonging to the Dean and Chapter at *Ely*, I took some decayed mortar, which was full of those saline shoots frequently seen on old walls, and boiled it in a proper quantity of water. The water be-

ing filtered and evaporated, afforded in great plenty fine, well-formed crystals of saltpetre: the crystals were taken out and dried, and the remaining part of the solution was again evaporated, and it again yielded very good saltpetre: but I could not observe, that there was any occasion for wood ashes to make any part of the solution crystallize, or that there were formed any crystals either of sea salt, or of any other salt, except saltpetre.

This experiment, which I repeated more than once, contradicts a very generally received opinion, namely, that saltpetre cannot be made from the rubbish of old buildings, without the concurrence of the salt separable from the ashes of burnt vegetables*.

It

* — nullum nitrum a nobis hic in Europa

It cannot be denied, that the vegetable fixed alkali is one of the constituent parts of saltpetre; but it is contended, that the burning of vegetables is not the only way of procuring that alkali, since we see, from this experiment, that it was as certainly formed in the mortar as the saltpetre itself was.

A few years ago, as some workmen were digging gravel near *Bury St. Edmund's*, they met with a large solid substance of a white colour, sur-

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ropa natum cognosci cujus nativitatem non ingreditur sal fixus qui in cineribus lignorum combustorumprehenditur. Boerh. Chem. Vol. II. p. 386. Nature affords no perfect saltpetre. — We may be assured that crystalline nitre, whencesoever it comes, has been manufactured by art; that art has supplied *its alkaline basis*, and reduced it into a crystalline form. Newman's Chem. p. 197.

rounded every way with gravel, and at the distance of twelve or fourteen feet from the surface. They at first mistook it for a lump of chalk; but upon tasting it, they found it to have the taste of saltpetre. I have a piece of the original lump in my possession. It is a solid mass, very hard; when dissolved and crystallized, it affords crystals, resembling in all their properties the purest saltpetre. Unless more care had been taken in examining the situation of this lump of saltpetre, when it was first discovered, it may be difficult to account for its production; but it is highly probable, that it was a natural production, and that the ashes of burnt vegetables had never been employed in its formation. The roots of horseradish penetrate very deep into the earth;

earth ; and upon inquiry I found, that horfe-radish grew upon the surface of the earth where this mass of faltpetre was formed. Whether this plant had contributed to its formation, may be a question worthy the reader's consideration, since we know that many plants, such as borage, fennel, the sun-flower, and tobacco, yield faltpetre.

Another observation which may be drawn from what has been advanced, respects the nature of those saline efflorescences which were found in the mortar, and are frequently to be met with on old damp walls, and from which the word faltpetre, or salt of stone (*sal petræ*), seems to be derived. Many authors* have

* See a Paper of the very ingenious Dr. Brown-

have affirmed, that the salt of these shoots is the mineral fixed alkali. I have reason, from my own experiments on the subject, to believe, that the affirmation is true in some instances; but it must not, I apprehend, be generally admitted, since we have seen that those shoots yield, in some circumstances, not the *mineral alkali*, but a perfect *saltpetre*.

With great diffidence I propose it to be considered, whether the same saline shoots which in some cases constitute the mineral fixed alkali, would not, if left to themselves on the same place where they are produced, be at length converted into saltpetre. The operation of nature
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Brownrig in *Philos. Transf.* for 1774. p. 485.
— *Opus Chym.* by Marggraaf, Vol. II.
p. 419. — *Cronstedt's Miner.* p. 143.

in spontaneously producing those shoots of mineral fixed alkali, is in no respect less wonderful than the conversion of the fixed alkali itself, by a longer process, into saltpetre. This conjecture, founded on the different qualities of these saline shoots, and the manner of their being produced, may receive some confirmation from the two following facts.

“ Near the city of *Xen Si* in *China* is a town, about which the land produces three things. One is the soap they use there, called *Kien*; they know nothing of our's. After it has rained, if the sun shine, there rise out of the earth certain bladders of thick froth, which are gathered to wash and whiten linen. The second is *saltpetre*; and *common salt* the third. Out of twenty pounds of earth, put
into

into a jar, and wrought after their manner, they get twelve pounds of salt, and three of saltpetre *.” It is probable, that the *Kien* here spoken of, as supplying the place of soap, consists in part or wholly of the mineral fixed alkali. “ Upon the coast of *Coromandel*, in a sandy soil, not far from the sea, the inhabitants gather every morning, an earth abounding with a natural alkali ; of this earth they make a ley, which being sharpened by quick-lime, they use in fixing their colours on their linen cloths. But if the alkali be left undisturbed upon the place where it is produced, it spontaneously changes itself into saltpetre †.”

If

* Churchill's Coll. of Travels, Vol. I. p. 49.

† — si vero suo generationis loco relin-

If this sandy earth was washed, common salt and saltpetre might probably be separated from it, as is done from the Chinese earth before mentioned, and the two accounts confirm one another. If these accounts

be

quitur alcali prædictum, *sponte in nitrum se transmutat.* — Miscell. Cur. Germ. ann. 9. & 10. p. 460. There is an account in the Philosophical Transactions for 1771. p. 567, of a fossile alkaline salt, found in the country of Tripoli in Barbary, which our callico-printers thought answered their purposes better than any other salt they had ever tried. This observation confirms what is said of the use of this salt found on the coast of Coromandel, and teaches us to attribute the excellency of the East India colours to the nature of the alkali used in fixing them. The French dyers use an alkali prepared from the burning of tartar and lees of wine: this alkali is of the purest kind; and the superiority of their colours over those of most other countries, has been attributed to the great purity of the alkali which they used. Memoires de Chem. Vol. II. p. 556.

be admitted, they will greatly tend to reconcile the different opinions of chemists concerning the nitre or *natron* of the ancients; some holding it to have been the mineral fixed alkali, and others esteeming it the same with our saltpetre; for it may in fact have been either one or the other, or a mixture of both, according to its age.

It may in the last place be remarked, that sea salt does not always accompany saltpetre in the earths where it is generated, since not a grain of sea salt could be obtained from a large portion of the decayed mortar. From the great quantities of sea salt usually found in saltpetre earths, some chemists* have conjectured, that sea salt was

* Baumé Chy. Vol. III. p. 599.

insensibly changed into saltpetre; and others have supposed, that the same natural process which produced saltpetre, produced also sea salt. The fore-mentioned experiment renders this last supposition somewhat doubtful; the matter however is not certainly established either way, and there is great room for further investigation.

This leads us to the consideration of a question of very difficult decision—how is saltpetre generated? I am not ashamed to own my inability to answer this question in a manner satisfactory even to myself. There are powers in nature in a great measure unknown to us, by which the parts of matter are subjected to perpetual change, and forced to assume arrangements from which new compounds are constantly

ly

ly resulting. The sweet, bitter, and aromatic juices of vegetables; the blood, bile, milk, urine, fat, and bones of animals, are all of them as different from the substances from which they are composed, as saltpetre is from the earth from which it is generated: but the one being a more common process of nature than the other, it does not so much astonish us, or excite our curiosity to account for it. The answer of the Spaniard who was asked if he knew how the saltpetre was yearly regenerated in his grounds, seems to include all that philosophy can say on the subject: “ I have two fields; in the one I sow wheat and it grows; in the other I collect saltpetre *.”

There

* Histoire Nat. de L'Espagne, by Bowles, p. 80.

There was a time when the air was looked upon by all chemists, as the great storehouse of saltpetre; and the earths in which it was found were supposed to have attracted it, ready formed, from the air. Instead of saltpetre in substance, some later philosophers have supposed that its acid part only exists in the air; and that this acid part, being attracted from the air, unites itself with the earths which yield saltpetre. Others are of opinion, that the acid of saltpetre does not float in the air as a substance distinct from it, but that it is one of the constituent parts of the air itself; and consequently, if saltpetre be formed by the earths attracting this acid, the air must be decomposed. I know not of any

well conducted experiments which are so conclusive in favour of this aerial origin of saltpetre, as one of Lemery's is against it. He put some lime into one dish, some salt of tartar into another, and a saltpetre earth, from which he had extracted the salt, into a third. He placed these three dishes in a situation open to the access of the air, and sheltered from the sun; he let them continue in that situation for two years; at the expiration of that term he examined their several contents, but no saltpetre had been generated in any one of them; tho' saline shoots had been formed on the walls of the place in which they stood. He afterwards mixed these same substances with animal matters, and after they had stood

stood a proper time, they all yielded him saltpetre*.

Saltpetre, it is granted, cannot be produced without air; but a simple exposure to the air of the materials in which it is most generally found, does not seem to be sufficient for the purpose: Air is necessary for the commencing and continuing of that intestine motion of the parts of vegetable and animal substances, which is called putrefaction; and I do not know whether the same may not be said of some minerals: hence, perhaps, it may not be a proposition far from the truth if we should say, that saltpetre is never produced in substances which have not undergone a putrefactive fermentation. Thus

U 2

Lemery

* Memoires de l' Academie des Scien. a Paris; ann. 1731.

Lemery got saltpetre as soon as he mixed with his earths animal substances, which ever tend to putrefaction. Fresh blood contains no saltpetre, but Kunckel extracted a large quantity from putrified blood. Fresh urine yields no saltpetre, but putrified urine yields it in great abundance, as may be gathered from the patent before mentioned, by which it was ordered to be saved for the making of saltpetre. Quicklime does not contain a particle of saltpetre; a mixture of fresh urine and quicklime, if examined soon after it is made, will not yield any; but after being suffered to putrify for six or seven months, very good saltpetre may be extracted from it*. All the common processes for making

* Chymie par M. Baumè, Vol. III. p. 594.

ing saltpetre imply the putrefaction of the materials. Now if it be allowed that saltpetre is never produced without some kind and degree of putrefaction, it may deserve to be inquired, whether in its mode of generation it has not some relation to two other substances universally produced by putrefaction ; I mean *fixed air* and *volatile alkali*. Many conjectures, not sufficiently warranted by experiment to be laid before the reader, present themselves on this head : one experiment, however, I will mention, especially as it is generally adduced by chemical writers in support of their theories concerning the origin and nature of the acid of saltpetre. When saltpetre and charcoal in powder are thrown together upon a fire, or any red-hot

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substance, the saltpetre is suddenly exploded, with a noise which is usually called *detonation*; much air is set at liberty; there arises a very copious condensable fume, and there remains, when the detonation is finished, a *fixed alkali*; that is, there remains one of the constituent parts of saltpetre; the other part, namely, the acid, is dispersed with the fume. This condensable fume has been collected, and it is said to contain nothing but water, mixed accidentally with a little fixed alkali, which is supposed to have proceeded from the alkaline basis of the nitre*. The liquor thus collected, is called the *clyffus* of nitre. I have frequently collected this liquor, and always found that it abounded with *volatile alkali*.

* Diction. of Chem. Art. *Clyffus*.

alkali. This volatile alkali may be rendered visible in a concrete form, by distilling the clyffus with a gentle heat. Is the nitrous acid formed from an union of fixed air with volatile alkali by means of putrefaction? What is fixed air, and what is volatile alkali, and how are they produced, are questions which want an explanation just as much as what is the acid of saltpetre, and how is it produced?

U 4 ESSAY

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OF
THE
MANUFACTURES
OF
GLASS

BY
J. H. W. & S. A. Y. & S. A. Y.

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E S S A Y IX.

Of the Manner of making Saltpetre in the East Indies.

THE reader will not be displeased with seeing some of the best accounts which I have met with in books on this subject, in the words of the several authors.

“ There is also a great deal of saltpetre vended at *Suratte*, which is made at *Afmer*, 60 leagues from *Agra*, out of the fattest ground, after it has lain fallow a considerable time. They dig certain trenches, which,

which, after they have filled with salt earth, they let in as much water as is sufficient to reduce it to the consistency of broth; and to soak it the better, they frequently tread it with their feet: when they judge the water has dissolved all the saline substance that was in the earth, they draw up the water into another trench, where in some time it thickens, when they boil it like salt, scumming it continually, and afterwards put it into earthen pots, where the dregs being settled to the bottom, they take it out again, and dry it to a hard substance in the sun *."

" The manner in which nitre is originally obtained in the East Indies,

* Harris's Collection of Voyages, Vol. II. p. 128.

dies, is (as I have it on the authority of a person of unquestionable veracity, who made it his particular business to procure a just information) according to the following account.

There is a very tall kind of grass growing in the country where the nitre is produced; which being burnt customarily in the autumn, forms beds of very large extent, covered with such salts and earths, resulting from the incineration, as are the most proper matrices for the formation of the nitre. These, lying all the winter on the sides of hills exposed to the winds, consequently collect the nitrous spirit from the air, in the same manner as when spread by art with that intent; and produce great quantities of nitre. After this a rainy season

ensues, which washes the salt down into the vallies; where the solution, partly absorbed by the earth, and partly flowing above it, is exposed to the heat of the sun, that makes an evaporation of the humidity, and leaves the salt in a dry state, either commixt with the earth, or on the surface of it; and this is sometimes artificially assisted, by turning the rills of water as they descend from the higher grounds by proper tanks, into places where the absorption of it by the ground is prevented; and where therefore the fluid drying away by insolation, produces a strong solution of the nitre; which being taken out and purified in that state, is afterwards reduced into a crystalline form by evaporation *."

“ Salt-

* Doëlle's Institutes of Chem. Vol. II. p. 321.

“ Saltpetre is likewise the produce of *Patna*. It is extracted from a clay, which is either black, whitish, or red. The manner of refining it, is by digging a large pit, in which this nitrous earth is deposited, and diluted with a quantity of water, which is kept stirred till it comes to a consistency. The water having drawn out all the salts, and the grosser parts subsiding at the bottom, the more fluid particles are taken out and put into another pit not so large as the former. This substance having undergone a second purification, the clear water that swims on the top, and is totally impregnated with nitre, is taken off and boiled in caldrons; it is scummed while it is boiling, and in a few hours a nitrous salt is obtained infinitely

finitely superior to any that is found elsewhere †. The Europeans export about ten millions of pounds for the use of their settlements in Asia, or for home consumption in their respective countries. It is bought upon the spot for three sols ($1d. \frac{1}{2}$) a pound at the most, and is sold again to us for ten (5d.) at the least ||.

By the enquiries which I have had an opportunity of making, from gentlemen who had long resided in the East Indies, I can only learn, that there are certain earths naturally impregnated with saltpetre, and that the inhabitants throw up these earths in

† I am ignorant of the particulars in which the East India nitre excels that made in different parts of Europe.

|| History of European Settlements in the East and West Indies. Eng. Transf. Vol. I. p. 340.

in little heaps, resembling the heaps in which lime is usually scattered over a field before it is spread; and at a proper season they extract the saltpetre, and crySTALLIZE it without making any use of the ashes of burnt vegetables. This method of making saltpetre is much the same with that practised in Egypt, as described by an author near an hundred years ago. The surface of the earth, we are told, where saltpetre is found, is in some places covered with a whitish crust; in others the salt is discovered by the taste of the earth. This earth is dug up, and being passed through a sieve, they steep it in water, and then boil the water till the salt falls to the bottom. All the gunpowder made in Egypt was formerly made of this salt-

saltpetre*; which shews the salt thus procured to have been not the mineral alkali, but a true saltpetre.

That this is a very possible method of making saltpetre is certain, not only from the experiment with the old mortar mentioned in the preceding Essay, but from what is constantly practised in Spain, where they extract large quantities of saltpetre from earths naturally impregnated with it, without having recourse to vegetable ashes. A third part of the uncultivated lands in Spain, is said to abound with saltpetre ready formed. These lands, where they are wrought for saltpetre, are turned over two or three times
in

* Toute la poudre qu'on fait en Egypt n'est fait que de ce nitre, qui est le vray saltpetre. Journ. de Sçavans 1685.

in the winter, and spring; and in August they throw the earth in heaps, and extract the saltpetre by pouring water on the earth, put into proper vessels, and crystallizing the solution. The earth, after the extraction of the saltpetre, is spread on the same ground from which it was taken, and at the expiration of twelve months it again becomes impregnated with saltpetre, and the same earths have for time immemorial annually produced the same quantity of saltpetre *. This Spanish earth resembles the Chinese earth, mentioned in the last Essay, in containing a large portion of sea salt, for they obtain from twenty to forty

* Hist. Nat. de l'Espag. p. 79. French Transf. 1778.

pounds of common salt from one hundred pounds of the earth : the crude saltpetre also as brought from the Indies, is greatly polluted with common salt. — Is the *common salt* in the Spanish earth, annually *re-generated* as well as the *saltpetre*?

The lands in Spain, says the author of its Natural History, if properly managed, would supply all Europe with saltpetre to the end of the world. In this circumstance Spain is more fortunate than England, as we are obliged to rely upon our importation from the East Indies for all the saltpetre we use. Spain however has not yet been able, or willing to furnish from its lands, saltpetre enough for its own consumption ; since it is obliged, occasionally, to have recourse to an im-
 2 portation

portation of that commodity from this kingdom.

The East India company had their first charter granted in 1600 : in the year 1628 they published their petition and remonstrance to the House of Commons. From this tract it appears, that they had good quantity of saltpetre then in store, and that they weekly made about thirty barrels of gunpowder at their own powder mills, from such refined saltpetre as they brought from the Indies. By their charter, granted in 1693, they were bound annually to supply government with 500 tons of saltpetre at 38*l.* 10*s.* a ton in time of peace, and at 45*l.* in time of war.

The following tables were extracted from the custom-house books,

by a person on whose accuracy I could depend.

Saltpetre imported annually into England for seven years ending at Christmas 1769.

	C.	q.	lb.
From Xtmaz 1762 to Xt. 1763—	425	80	2 26
1764—	226	92	3 6
1765—	353	99	3 7
1766—	413	13	0 0
1767—	374	24	2 22
1768—	338	40	3 26
1769—	344	37	3 0
<hr/>			
Total imported in 7 years —	247	689	3 3
<hr/>			

This quantity gives an annual medium of 3963036 lb *.

About

* The Dutch East India fleet in 1709, imported 2175370lb. of saltpetre; (Schelhamer de nitro. p. 82;) yet notwithstanding the great quantities of saltpetre which are annually brought into Europe from the East Indies, it is reckoned that two-thirds of the whole produce of that commodity are sent into

Saltpetre exported from England, from Christmas 1762 to Christmas 1769.

Exported to	1763. C. q. lb.	1764. C. q. lb.	1765. C. q. lb.	1766. C. q. lb.	1767. C. q. lb.	1768. C. q. lb.	1769. C. q. lb.
Denmark and Norway	292 0 3	780 3 8	276 2 10	588 1 18	97 1 21	.....	634 2 0
East Country	123 3 15	701 1 27	.....	.....	.....	.....	.....
Flanders	11 3 9	147 1 19	125 0 22	391 1 16	603 0 4	115 0 15	103 0 14
France	20 0 0	.....	.....	.....	473 1 7	.....	.....
Germany	202 2 0	642 0 14	254 2 18	91 3 21	119 3 17	.....	1,761 0 11
Holland	2,216 1 7	11,518 3 10	4,864 0 0	3,485 1 3	1,742 1 12	61 0 13	.....
Ireland	389 3 6	329 0 0	419 1 14	570 1 18	1,296 2 0	538 0 9	1,609 3 2
Italy	.....	.....	.....	.....	.....	.....	59 0 27
Portugal	.....	8 3 4	2,018 2 0	84 1 0	82 0 0	70 1 0	20 0 0
Spain	3,603 2 6	.....	.....	247 2 10	1 1 4	.....	.....
Streights	243 2 16	1,976 2 12	.....	.....	.....	.....	.....
Turkey	.....	.....	.....	.....	.....	.....	60 0 8
Antigua	.....	.....	.....	0 1 8	.....	0 2 0	.....
Barbadoes	1 1 11	7 2 0	1 3 12	4 3 18	4 0 11	4 0 21	7 0 22
Canada	22 0 0	0 2 14	.....	.....	0 2 24	.....	2 1 10
Carolina	50 1 10	28 0 16	39 1 0	27 0 7	22 0 10	25 2 6	34 3 11
Georgia	4 2 0	.....	6 1 2	3 0 0	1 3 7	5 2 0	12 3 0
Florida	.....	1 0 0	.....	.....	.....	0 2 0	.....
Jamaica	.....	3 3 14	1 2 18	1 3 19	3 0 12	2 0 20	2 3 16
New England	15 3 12	21 3 0	13 0 0	8 2 14	20 3 0	44 2 8	22 2 7
New York	6 3 0	2 2 11	3 1 0	6 0 20	7 2 7	12 3 0	6 2 19
Nova Scotia	.....	.....	.....	.....	0 2 4	.....	.....
Pennsylvania	10 3 14	21 1 0	8 1 0	52 2 8	23 3 17	49 1 20	37 0 0
St. Christopher's	.....	.....	.....	.....	1 1 2	.....	.....
Virginia and Maryland	6 3 0	9 3 17	20 2 2	25 3 6	47 2 12	43 0 2	48 2 10
Totals	7,221 3 25	16,201 3 8	8,052 1 14	5,589 2 18	4,549 1 3	972 3 2	4,422 2 17

Total exported in 7 years—47,010 C. 2 q. 3 lb. This quantity gives an annual medium of 752,168 lb.

About the same period that the government of England bargained with the East India company for an annual supply of saltpetre, a much larger quantity was made in France; an author of good credit * informing us that in the year 1691 the saltpetre which was made in the several districts of that kingdom, amounted to — 3647767½ pounds. This is a vast quantity, being nearly equal to the average quantity annually imported by our East India company. The French very wisely keep up their establishments for the making of saltpetre; the revolutions which have formerly taken place in India, render it not improbable, that similar

X 3: ones.

into China, and other parts of Asia, to be used in fire-works.

* See Memoires d' Artillerie par Sr. Surin-
rez, Tom. II. p. 104. Amster. 1702.

ones may take place again; and England would feel the distress which would attend the non-importation of saltpetre from the East Indies, more sensibly than any other state in Europe. This danger has not been adverted to by any Minister; but if the prevention of it should ever engage the attention of the legislature, the methods of making saltpetre which are followed in France, would deserve to be considered. For my own part I can have no doubt, that a plan might be contrived for the making of saltpetre in every county of this kingdom, by the very moderate labour of those, whose idleness is at present a burden to themselves, and a reproach to the police of the community, the *paupers* of the several parishes.

E S S A Y X.

*Of the Time when Gunpowder
was discovered.*

THE history of the discovery of gunpowder is involved in much obscurity; the most ancient authors differing from each other in their accounts of this matter, and many of them confounding two distinct inquiries; — the discovery of the composition of gunpowder; — and the discovery of the means of applying it to the purposes of war.

Father *Kircher* * affirms, that without controversy we ought to attribute the invention of gunpowder to *Barthold Schwartz*, or Barthold the Black, a monk of Goslar in Germany, and a profound alchemist. This man having mixed together, with a medical view, *nitre*, *sulphur*, and *charcoal*, a spark accidentally fell upon the mixture, blew up the pot in which it was contained, and caused a dreadful explosion. The monk, astonished at the event, made several repetitions of his experiment, and thereby fully discovered the nature of gunpowder, in the year 1354. *Kircher* gives us also, out of a very old German book which he professes to have read, a monkish account of the first use which *Schwartz* made of his

* *Kirch. Mun. Sub. p. 487.*

his gunpowder; he employed it to frighten some robbers from their haunts in the woods.

Sebastian Munster says, that he was well informed by a very eminent physician, that the Danes used guns in naval engagements in the year 1354, and that a chemist called Schwartz was the first inventor of them †. *Pontanus*, the Danish historian, accedes to this opinion.

Polydore Vergil, who died in the year 1555, attributes the discovery of gunpowder to some very ignoble German, whose name he wishes might never be handed down to posterity.

† Achilles Gassar^{us} medicinæ doctor, et historiographus, diligentissime scripsit mihi, Bombardas anno Christi 1354, in usu apud mare Danicum fuisse, primumque inventorem et autorem extitisse chymistam quendam nomine Bartholdum Schwartzum monachum. Munster. Cosmogr. Univ. Lib. 3. C. 174.

posterity. He further informs us, that this German invented also an iron tube, and taught the Venetians the use of guns in the year 1380*.

This is the common account of the discovery of gunpowder; its truth however is rendered doubtful by what follows.

The battle of *Cressy* was fought in the year 1346; and an historian who lived at that time is quoted by *Spondanus* as affirming, that the English greatly increased the confusion the French had been thrown into, by discharging upon them from their cannon hot iron bullets†. Three years before the battle of *Cressy*, the Moors were besieged

* Polyd. Verg. de Inven. Rerum. Lib. II. C. XI.

† Spond. Ann. Eccle. ann. 1346.

sieged by the Spaniards in the city of *Algeziras*; and we learn from *Mariana*, the Spanish historian, “ that the besieged did great harm among the Christians with iron bullets they shot:” the same author adds, “ this is the first time we find any mention of gunpowder and ball in our histories *.” The *Earls* of *Derby* and *Salisbury* are mentioned by *Mariana* as having assisted at the siege of *Algeziras*; and as they returned to England in the latter end of the year 1343, it is not an improbable conjecture, that, having been witnesses of the havock occasioned by the Moorish fire-arms, they brought the secret from Spain to England, and introduced the use of artillery into the English army at the battle of *Cressy*.

* *Mariana's Hist. of Spain, Eng. Transf.*

Cressy. The use of guns in Spain in the year 1343, is proof sufficient either that Schwartz was not the inventor of gunpowder, or that Kircher and others are mistaken in fixing his discovery so late as the year 1354.

There is reason, however, to believe, that both gunpowder and guns were known in Germany at least forty years before the period assigned by the Spanish historian for their first introduction into Spain. In the armoury at *Amberg*, in the Palatinate of *Bavaria*, there is a piece of ordnance, on which is inscribed the year 1303 †. This is the earliest account

I have

† Quam opinionem (of Schwartz being the inventor of gunpowder) generosissimus Stettenius refutat, cum ex eo quod Ambergæ Palatinatûs Superioris in officina armorum reperiatur tormentum militare cui sit annus 1303 inscriptus. *Acta Erud.* 1769. p. 19.

I have yet met with of the certain use of gunpowder in war; and it seems probable enough, as the *Pope* and the *Duke of Bavaria* are thought to have been the first princes who made saltpetre in Europe*.

It ought not to be concealed from the reader, that *Camerarius* quotes a Danish historian as relating, that *Christopher*, king of the Danes, was killed in battle by the stroke of a gun, in the year 1280†. Upon examining the passage quoted by *Camerarius*‡, it is only said, that *Christopher*, the son of king *Waldemar*, was killed

* Clarke's Nat. Hist. of Saltpetre.

† Cranzius scribit Christophorum Danorum regem in prælio bombardæ ictu occisum anno 1280. Camera. Hor. Subf. Con. p. 3. 312.

‡ Cranzius Vandal. Lib. VIII. C. 23.

killed in the beginning of an engagement by a gun, a warlike instrument then lately discovered. Now it appears*, that Waldemar, Christopher's father, did not succeed to the crown of Denmark till the year 1332, and that his son was killed in a naval engagement; several years afterwards †, probably about the time assigned by Munster for the first use of gunpowder in Denmark.

But we are able, upon good grounds, to carry the discovery of gunpowder to a period antecedent to the date of the Amberg piece of ordnance; and it is probable enough, that its composition was known long before we read any thing of its use in war.

Roger

* Cranzius Danicæ. Lib. VII. C. 32.

† Id. Lib. VII. C. 38.

Roger Bacon died at Oxford in 1292. In the printed copies of the works of this renowned Monk, there are two or three passages, from which it may fairly be inferred, that he knew the composition of gunpowder*; and a manuscript copy is said to have been seen †, wherein *saltpetre*, *sulphur* and *charcoal* are expressly mention-

* In omnem distantiam quam volumus, possumus artificialiter componere ignem comburentem ex sale *petræ* et *aliis*. R. Bacon de Mirab. Potes. Artis et Naturæ. Epist. C. VI. — sed tamen salis *petræ* *Luru vopo vir Can utriet sulphuris* et sic facies tonitrum et coruscationem, si scias artificium. Id. ib. C. XI. It is very probable, that in the first of these passages, Bacon concealed sulphur and charcoal under the word *aliis*; and that in the last, having mentioned saltpetre and sulphur, he concealed charcoal and the method of mixing the three ingredients, under the barbarous terms, *Luru vopo vir can utriet*.

† Plott's Nat. Hist. of Oxfordshire.

mentioned, as the ingredients of a composition which would burn at any distance. But though it be allowed, that Bacon was well acquainted with the composition of gunpowder, it will not follow, either that he was the first discoverer of it, or that he knew its application to fire-arms.

The Moors, we have seen, who had settled in Spain, are esteemed by some to have been the first persons who used gunpowder in the practice of war; they also brought into Europe a great many Arabian books, and introduced a taste for chemistry into different countries, about the time in which Bacon flourished. It is confessed, on all hands, that Bacon was no stranger to Arabian literature; a great part of his optical dis-

disquisitions, being evidently borrowed from *Albazen* the *Arab*; and it is not a supposition wholly void of probability, that he derived his knowledge of the composition of gunpowder from the same source. As to his knowledge of the use of it in war, he certainly had some idea of it; for he intimates, that cities and armies might be destroyed by it in various ways: but it is not equally certain that he had any specific notion of the manner of using gunpowder, which unquestionably prevailed soon after his death.

It is one thing to throw out a conjecture concerning the effects which might be produced by the proper application of a known substance; another, to describe the

means of applying it. There are substances in nature, from a combination of which it is possible to destroy a ship, or a citadel, or an army, by a shower of liquid fire spontaneously lighted in the air : every person who is aware of the dreadful fiery explosion which attends the mixture of two or three quarts of spirit of turpentine with strong acid of nitre, must acknowledge the truth of the assertion ; but the simple knowledge of the possibility of effecting such a destruction, is a very different matter from the knowledge of its practicability ; though future ages may, perhaps, invent as many different ways of making these substances unite in the air, so as to fall down in drops of fire, as have been in-

2

vented

vented of making gunpowder, a sad instrument of the destruction of our species since the time of Bacon.

From the accounts given of the attempts of *Salmones* and *Caligula* to imitate thunder and lightning, some have been of opinion that gunpowder was known to the ancients*: be that as it may, we cannot hesitate in admitting that it has been long known in various parts of Asia. It would be useless to cite a variety of authorities in proof of this point; I will content myself with that of Lord Bacon:—"Certain it is, that ordnance was known in

* See Duten's Enquiry into the Discoveries of the Moderns, p. 263. English Translation.

in the city of the Oxidrakes in India; and was that which the Macedonians called thunder and lightning, and magick. And it is well known that the use of ordnance hath been in China above 2000 years *."

One of the most useful applications of gunpowder, is in the art of mining. The hammer and metallic wedges were probably the first instruments which men used for the splitting of rocks. The application of wooden wedges to the same purpose, seems to have been a more recent discovery: it is the property of dry wood to expand itself, when wetted with water: miners have had ingenuity enough to avail themselves of this
pro-

* Bacon's Essay on the Vicissitude of Things.

property, for it is a practice with them to drive wedges of dry wood into the natural or artificial crevices of rocks, and to moisten the wedges with water. Wood, by imbibing moisture, swells in every dimension; and the force of this expansion is sufficient, in many cases, to detach large pieces from the main body of a rock. But the expansive force of gunpowder is incomparably greater than that of moistened wood. There are different accounts of the time when gunpowder was first applied to the blasting of rocks. “ *Rossler* relates that in 1627, the blasting of mines was brought from *Hungary*, and introduced in the *German* mines: but *Beyer* says, that in 1613, it was in-

vented by *Martin Freygold* at *Freiberg**.”)

In answer to an inquiry which I made concerning the time when blasting was introduced at the famous copper mine at *Eaton* in *Staffordshire*, I received the following account from a very able and intelligent person. “ I can give you a little better information concerning the affair of blasting. I have known that country where the mine is, above fifty years; and have often seen the smith’s shop in which, tradition says, the first boring auger that had ever been used in England was made; and that the first shot that was ever fired in *Derbyshire* or *Staffordshire*, was fired in this

* See *Travels through the Bannat, &c.* by *Baron Born*. Eng. Transf. p. 192.

this very copper-mine at Ecton. The inhabitants of Wetton (a village adjoining to the mine) tell me the auger was made by some *German* miners, sent for over by *Prince Rupert* to work this copper mine at Ecton. The Prince (Rapin says) came into England in 1636, and was ordered by the King to leave the kingdom 1645; and though he was afterwards admiral under Charles the Second, it is most probable the miners came during his first abode in this kingdom. I am very well convinced of the truth of the above tradition, because the fathers of my informers might be very well acquainted with the miners that introduced blasting among them." In addition to this account I would observe, that the manner of splitting

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rocks

rocks by gunpowder, as practised at *Liege*, was published by the Royal Society in 1665; and that it was not till about the year 1684, that the miners in Somersetshire began to use gunpowder *. In the year 1668 Prince Rupert was chosen governor of the *Society for the Mines Royal* †; and as he lived fourteen years after that appointment, it is not improbable that he might send for the German miners in consequence of his connexion with that society.

Before the discovery of blasting rocks by gunpowder, it was the custom in our English mines, as well as in Germany, to split them by wood fires. This method is minute-
ly

* *Philos. Transf.*

† *Account of Mines*, p. 20.

ly described by Agricola *, and it is not yet wholly fallen into disuse †. It is a very ancient mode of mining, being mentioned by Diodorus Siculus, as practised in some Egyptian mines §: he gives us, in the place here referred to, such a melancholy account of the condition of the poor slaves who were employed in those mines, as must make the heart of every humane man, who has a rational respect for the natural rights of every individual of our species, swell with indignation, and thrill with horror. Would to God, that the clemency of the taskmasters in the mines of *Peru*, and in other settlements of European *Christians*, could

* De Re Metal.

† Philos. Transf. 1777. p. 414.

§ Lib. III, .

could induce us to believe that Diodorus Siculus had exaggerated the barbarity of *Heathen* policy ! But there is much to be done, much, I fear, to be suffered, by all the states of *Christendom*, before the Gospel of Christ can be said to be established amongst them as a rule of life influencing their conduct.

It is related of *Hannibal*, that he opened himself a passage through the Alps, by applying fire and vinegar to the Rocks which opposed his route. This mode of splitting rocks was, probably, not invented by Hannibal ; he might have had frequent opportunities of observing a similar practice in the silver mines in Spain, which daily afforded him three hundred pounds weight

weight of silver*. There is nothing, indeed, said of vinegar in the description of the Egyptian mines before mentioned; but Pliny expressly affirms, that it was the quality of vinegar, when poured upon rocks, to split such as an antecedent fire had not split; and that it was the custom of miners to burst the rocks they met with, by fire and vinegar †. This account of Hannibal's using vinegar in

* Mirum adhuc per Hispanias ab Hannibale inchoatos puteos durare, sua ab inventoribus nomina habentes. Ex quibus *Bebulo* appellatur hodieque, qui CCC pondo Hannibali subministrabat indies! Plin. Hist. Nat. L. 33. S. 31.

† Saxa rumpit infusum (acetum) quæ non ruperit ignis antecedens. Plin. Nat. Hist. L. 23. S. 27. & L. 33. S. 21. where by *Silices* cannot be understood what we call flints, since vinegar has no action on flints.

in splitting the rocks, is generally looked upon as fabulous: for my part, I can easily conceive, that a few barrels of vinegar might have been of great use, if the rocks were of the limestone kind; and, whether they were so or not, I leave to be settled by those, who have visited the place where this famous attempt was made. Vinegar corrodes all sorts of limestone and marble rocks; and hence, being introduced into the cracks made by the fire, it might be very efficacious in widening them, and rendering the separation of large lumps by iron crows and wedges more easy. It is erroneously supposed, that a large quantity of vinegar was requisite, for the vinegar did not reduce the whole mass
of

of rocks into a pulp; since Livy clearly informs us, that after the action of both the fire and vinegar, they were obliged to open their passage by *iron* instruments, which would have been wholly unnecessary, had the main body of the rocks been dissolved by the vinegar *.

* — ardentiaque saxa infuso aceto putrefaciunt. Ita torridam incendio rupem *ferro* pandunt. Liv. Hist. l. xxi. c. xxxvii.

END OF VOL. I.

